Technical Report

National Energy Board
Office national de l'énergie

Conventional Heavy Oil Resources of the Western Canada Sedimentary Basin

August 2001

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Acronyms

API	American Petroleum Institute
EUB	Alberta Energy and Utilities Board
GSC	Geological Survey of Canada
IVIP	Initial Volume In Place
OIP	Oil In Place
PADD	Petroleum Administration Defence District
PEEP	Petroleum Economic Evaluation Program
PETRIMES	Petroleum Resource Information Management and Evaluation System
RF	Recovery Factor
SAGD	Steam Assisted Gravity Drainage
SEM	Saskatchewan Department of Energy and Mines
VAPEX	Vapour Extraction
WCSB	Western Canada Sedimentary Basin
WTI	West Texas Intermediate

FOREWORD

The National Energy Board (the Board or NEB), as part of its regulatory mandate, continually monitors the supply of all energy commodities in Canada (including electricity, oil, natural gas, and their by-products) and the demand for Canadian energy commodities in both domestic and export markets. The Board's Supply and Demand Reports provide a long-term outlook for the supply and demand for all energy commodities. The Board's Energy Market Assessment Reports address issues within a specific commodity. The Board also publishes, from time to time, reports of a technical nature focussing on specific commodity issues. *Conventional Heavy Oil Resources of the Western Canada Sedimentary Basin* is the latest of these technical reports.

The report presents the results of an extensive review of Canadian conventional heavy crude oil resources and is focussed on examining and updating estimates of the volume of conventional heavy oil contained in the ground (oil in place). Estimates are also provided for that portion of the oil in place that is recoverable. These estimates consider both the volume available from current technology and production practices, and the potential volume from future technologies which could increase recovery levels.

The results of an analysis of supply costs are also provided, as is a discussion of the relative economics of conventional heavy oil production. During the preparation of *Conventional Heavy Oil Resources of the Western Canada Sedimentary Basin*, a series of meetings and discussions were held with government agencies, petroleum research organizations, and operating companies involved in the exploration for, and production of conventional heavy oil. The Board thanks all those who provided their input, with special thanks to the Geological Survey of Canada for its contribution.

The Board welcomes any comments on the design, use of the selected methodology, or on the results of this report. Comments should be directed to the Secretary, National Energy Board, 444 - Seventh Avenue SW, Calgary, Alberta, Canada T2P 0X8.

EXECUTIVE SUMMARY

Conventional Heavy Oil Resources of the Western Canada Sedimentary Basin has been undertaken as part of the Board's regulatory mandate of monitoring the Canadian supply of energy commodities. The nature of Canada's oil supply, especially in Western Canada, has been changing. This report focuses on the current and future supply availability of conventional heavy oil in Canada.

The Board generally defines conventional heavy oil as crude oil that is found in a liquid state in the ground, has the ability to flow into a wellbore, and has a specific gravity greater than 890 kg/m^3 (API gravity of less than 25°).

Conventional Heavy Oil Resources of the Western Canada Sedimentary Basin provides an overview of the contribution of conventional heavy crude oil to Canada's total oil supply. It describes how the Board conducted the study and follows with the results of the study, which are provided on a geological play basis.

Highlights of the report include the following:

- The results indicate that resources of conventional heavy oil have been understated in the past. The Board's analysis indicates that the oil in place for the studied plays has increased by 20 percent, to 7 927 million m^3 (49.9 billion barrels)[1], from the estimate of 6 575 million m^3 (41.4 billion barrels) provided in the Board's 1999 Supply and Demand Report. This increase in the oil in place estimate can be attributed to the fact that this study projects the existence of a significantly greater number of smaller-sized pools compared with previous studies.
- This analysis shows that 21 percent of the discovered resources, and 12 percent of currently undiscovered resources, can be technically recovered. These estimates include the contributions from the application of present day, proven technology and production practices, and the potential for improved recovery through the application of future technologies. The ultimate recoverable resources of heavy conventional crude oil in Western Canada are thus estimated to be some 1 391 million m^3 (8.7 billion barrels), representing an increase of 8.2 percent compared with the Board's 1999 Supply and Demand Report.
- Finally, the Board estimated the supply cost to develop conventional heavy oil pools in Western Canada in the future, based on a cost review of present day heavy oil operations. This study projects that 65 percent of the technically recoverable volume can be recovered economically, if producers would be willing to absorb costs of at least $Cdn 62.38/$m^3$ ($Cdn 9.91/bbl) in the field. If producers would absorb a cost of $Cdn 83.91/$m^3$ ($Cdn 13.02/bbl), 80 percent could be recovered economically.

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[1] One cubic metre (m^3) of crude oil is approximately equal to 6.3 barrels or one metric tonne.

CHAPTER ONE

1. Introduction

In 2000, Canada produced crude oil from a number of areas, including conventional light oil from Western Canada, the Northwest Territories, and from Hibernia (offshore Newfoundland); conventional heavy oil from Western Canada; and bitumen and synthetic crude oil from the oil sands in northern Alberta. *Conventional Heavy Oil Resources of the Western Canada Sedimentary Basin* examines the prospective future supply of conventional heavy oil in Western Canada, and is intended for a technical audience that is familiar with the terminology and concepts of resource assessment.

There are no oil sands volumes accounted for in this report. Readers are referred to the Board's report entitled *Canada's Oil Sands: A Supply and Market Outlook to 2015*, published in October 2000, for a discussion of the oil sands resources.

In general, the Board defines conventional heavy oil as crude oil that is found in a liquid state in the ground, has the ability to flow into a wellbore, and has a specific gravity greater than 890 kg/m^3 or an API gravity of less than 25°. For the purpose of this report, both Saskatchewan medium and heavy oils are combined in the Board's classification. Some additional conventions used in preparing this report are listed below:

- Generally, resource volumes are given as million m^3 (million cubic metres).
- Dollars are year 2000 Canadian, constant, unless stated otherwise.
- Future improved recovery has two components. The first relates to the optimization of production and initiation of additional recovery projects, based on currently commercialized technology. The second component relates to improved recovery through the future application of technology not yet available. In the main body of this report, the discussion of the resource potential of the various plays generally uses the term in the first sense, but estimates of the second component are provide in a summarized form.

The Board's projection of conventional heavy oil production in the 1999 Supply and Demand Report[1] was based on estimates of heavy oil resources published by the GSC[2] in 1998, the Board's own long-term forecast of an $US 113.26/m^3 ($US18/bbl) oil price (WTI), the results of a cash-flow model, and trend analysis of heavy oil production. A price sensitivity projection, based on $US 138.43/m^3 ($US22/bbl) was also provided. During the preparation of that report, it became apparent that although the historical trend of heavy oil production continued to ramp upwards, this trend could not be sustained for long. The diminishing volume of remaining recoverable reserves dictated a relatively steep decline would have to occur in the next few years. It became clear that an updated view of the conventional oil resource picture was necessary. This report attempts to address that concern.

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[1] *Canadian Energy Supply and Demand to 2025*, National Energy Board, 1999

[2] GSC Open File 3674, *Oil Resources of Western Canada*, Lee, P. J., 1998

In 2000, conventional heavy oil production from the Western Canada Sedimentary Basin (WCSB) averaged 91 300 m^3/d (574,000 bbls/d) and represented 26 percent of total Canadian production. This volume is 10 percent and six percent higher than in 1999 and 1998, respectively, and is 10 percent higher than the peak production that had been projected in Case 1 of the Board's 1999 Supply and Demand report. This increasing level of heavy oil production reinforces the need for an updated resource assessment.

Conventional light oil production from Western Canada continues to decline on an annual basis, averaging 108 800 m^3/d (684,000 bbls/d) in 2000, only 19 percent higher than conventional heavy oil production. The gap between the conventional light and heavy production is expected to continue to narrow with heavy oil production exceeding light oil production before 2010.

Canadian heavy crude oil generally sells at a considerable discount compared with light crude oil, reflecting the relative market value of end products to the refiner. This discount can vary widely depending on market conditions. Historically, the light/heavy price differential, commonly defined as the price difference between Light Par at Edmonton and Bow River Heavy Blend at Hardisty, Alberta has ranged between $Cdn 18.88 and 56.63/m^3 ($Cdn 3 and 9/bbl), averaging about $31.46/m^3 ($5/bbl). Generally, when heavy oil supply is tight relative to demand, the differential decreases and vice versa. In the past year, the differential has increased substantially, peaking at $134.34/m^3 ($21.35/bbl), offsetting much of the benefit of higher international oil prices. This spike in the differential was caused primarily by market conditions in U.S. PADD II, where lighter grades were preferentially run to meet increased demand for distillate and gasoline. Higher natural gas prices, which reduced the amount of natural gas liquids available for refinery blending and which also led to some fuel switching from natural gas to distillate, and cold winter weather, which disrupted the transportation of heavy crude, also supported a wider differential. The differential has moderated somewhat since then to $101.05/m^3 ($16.06/bbl) in May 2001. Heavy oil generally costs more to produce than light oil, further impacting producers' cash flow.

The Board expects to use the results of this study to assist in its projection of future conventional heavy oil production to be published in its next Supply and Demand report, targeted for release in early 2003.

CHAPTER TWO

2. Previous Work

The number of known assessments of heavy oil resources in the WCSB is relatively small in comparison with the number of assessments that have been done for natural gas. Recent efforts made at assessing the oil resources include two studies completed by the GSC[1] (1988 & 1998) and one study by Bowers[2] (2000). The nature and conclusions of these studies are discussed below.

2.1 Conventional Oil Resources of Western Canada (Light and Medium), GSC, 1988

In 1988, the GSC published its first report on remaining conventional light and medium oil resources in the WCSB. It provided a comprehensive analysis of the resource endowment of the WCSB using geological, technical and statistical analyses. The report examined 78 established geological plays and an additional 49 conceptual plays. This GSC assessment used year-end 1984 reserves data from each of the provinces in Western Canada. The resource appraisal was done using the GSC's PETRIMES model and oil-in-place estimates for each discovered pool, both light and medium, to generate the undiscovered in-place volume for each established play. For conceptual plays, a subjective probability analysis was used. This subjective approach considered both the exploration risk that the play actually exists and probability risks for pool sizes. Average recovery factors representing a combination of primary and secondary recovery schemes were applied to the undiscovered pools that were considered to be large enough to cover the estimated drilling and development costs.

The GSC recognized 2 360 million m^3 of recoverable oil (7 377 million m^3 of oil in place) as already discovered in the established plays, an additional 509 million m^3 of recoverable oil left to be discovered in those same plays, and 61 million m^3 of undiscovered recoverable oil in conceptual plays. The established reserves were estimated to be contained within about 3,300 separate pools. The undiscovered potential from the established plays was expected to be found in about 4,000 new pools that were expected, for the most part, to be smaller in size than pools already found. Using half-cycle costs (discovery costs excluded) it was estimated that 70 percent of the undiscovered volumes could be recovered economically at an oil price of $Cdn 94.38 to 141.58/m^3 ($Cdn 15.00 to 22.50/bbl), dollars of the day. In comparing this assessment with the Board's current report, almost all of the plays studied by the Board were included in GSC's 1988 report. The GSC's assessment did not include the Cretaceous heavy oil volumes found in the Lloydminster Region of Alberta and Saskatchewan.

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[1] GSC Paper 87-26, *Conventional Oil Resources of Western Canada (Light and Medium)*, Podruski, J. A., et al, 1988

[2] Bowers, B. November 2000, *Conventional Natural Gas Resources of the Western Canada Sedimentary Basin*, in Journal of Canadian Petroleum Technology

2.2 Oil Resources of Western Canada, GSC 1998

In 1998, the GSC published its second report on remaining conventional oil resources in the WCSB. Using a similar approach to that used in its first report, 69 established and 25 immature (conceptual) plays were reviewed to estimate the resource potential. The assessment was done using year-end 1994 data from each province in Western Canada. The GSC used its PETRIMES model, with the oil-in-place estimates of individual pools, both light and heavy, to generate the undiscovered in-place volumes for established plays. For conceptual plays, the GSC used a non-parametric discovery process model. In this case, the expected values of the play potential and discovery dates were used to generate a play resource discovery sequence, which was analysed using the same method as the established plays. This report recognized discovered oil-in-place resources of 12 547 million m^3 in the established plays, an additional mean value of 5 488 million m^3 of undiscovered oil in place in the established plays and 1 470 million m^3 of undiscovered oil in place in the immature plays. The discovered resources were contained in 7,142 oil pools. The undiscovered potential in established plays was expected to be found in over 18,000 pools, most of which are expected to be smaller in size than the discovered pools. This GSC report did not contain an estimate of recoverable volumes nor did it provide an economic assessment of the undiscovered potential. The report did assess Cretaceous heavy oil plays in the Lloydminster Region and provided a detailed assessment of the Cretaceous plays across the Basin. The GSC assigned pools to light or heavy categories based on a single specific gravity cut-off (900 kg/m^3 or 24° API) for the entire Basin.

In the 10 years between the GSC reports, discovered conventional oil resources in Western Canada for those plays studied in both reports grew from 7 153 to 9 549 million m^3 of oil in place, a growth of 33 percent. It should be noted that the number of designated pools doubled from 2,612 to 5,245, which confirms that new pools are generally smaller than previously discovered pools. For undiscovered conventional oil resources, the mean potential estimate grew from 1 874 to 3 492 million m^3 of oil in place, a growth of 86 percent. The number of undiscovered pools expected to be found increased from 3,133 to 12,126, a growth of 287 percent. This illustrates that the size of discovered pools are expected to be smaller in the future. New technology, in particular 3D seismic and horizontal drilling, in that 10 year period reduced the cost of finding and developing smaller pools.

2.3 Conventional Natural Gas Resources of the Western Canada Sedimentary Basin, Bowers 2000

In 2000, Bowers published an estimate of conventional natural gas which included an estimate of conventional crude oil of 16 000 million m^3 of oil in place in the WCSB. His estimate was 18 percent lower than the most recent GSC estimate. It was generated by plotting the discovery rate of conventional crude oil on an annual basis against the cumulative discovered oil-in-place resources. The discovery rate is a reflection of the amount of oil added for every metre of drilling in the basin that is specifically directed for oil. The number of oil-directed metres drilled, in any particular year, is the total metreage of all exploratory and development wells that are classified as oil wells, plus a proportional share of the dry hole metreage. The resulting exponential decline curve is projected out to the point where there is no additional oil added by drilling more exploratory wells.

Bowers' study reviewed data from 1965 to 1997 on an annual basis; however, the resources found prior to 1965 and the amount of drilling to that date were included. At year-end 1997, there were about 14 000 million m^3 of known resources. Therefore, this study estimated the undiscovered oil-in-place resources of conventional light and heavy crude oil in the WCSB to be 2 000 million m^3.

Table 2.1 shows the comparative results of these three studies.

TABLE 2.1

Summary of Previous Studies

	GSC 1988	GSC 1998	Bowers 2000
Discovered Oil In Place (10^6m^3)	7 377	12 547	14 000
Number of Discovered Pools	3,300	7,142	NA
Undiscovered Oil In Place (10^6m^3)	1 874	6 958	2 000
Number of Undiscovered Pools	4,000	18,000	NA
Total Oil In Place (10^6m^3)	9 251	19 505	16 000

3. Methodologies

This chapter describes the geological, engineering and economic analyses used and provides an overview of the consultation process.

3.1 Geological Data Analysis – Overview

The NEB used a discovery process model to generate its estimates of undiscovered potential in the geological plays. Year-end 1998 data was used for British Columbia, Alberta and Manitoba, and year-end 1997 data for Saskatchewan.

The geological plays as defined by the GSC in its 1998 report were adopted, generally without revision, in this assessment. The oil-in-place volume for each discovered pool in each of the studied geological plays was entered into a spreadsheet, along with the field name, pool name, date of discovery and specific gravity. This information was then provided to the GSC to run in its PETRIMES discovery process model. The output data from PETRIMES was inconsistent on a statistical basis and the Board agreed with the GSC's subsequent recommendation to use the geo-anchored discovery process method. The output data consisted of a range of oil-in-place volumes for each undiscovered pool. The Board used the mean pool size estimate for each undiscovered pool to complete the Basin assessment. As with any model, the reliability of the output data is dependent on the reliability of the input data. While the Board made a concentrated effort to validate the input data used, the intensive detailed stratigraphic analysis required to validate each specific pool was considered to be beyond the scope of this study. Therefore, reliance on the provincial agencies' analysis and naming conventions was required. As a general observation, discovery process model outputs tend to be conservative in nature, so the full potential may be somewhat higher than stated in this report.

3.2 Reservoir Data Analysis – Overview

The recovery factors for the discovered pools were adopted from the provincial databases. These recovery factors pertain mostly to primary recovery in the heavy oil pools, but some pertain to enhanced recovery. To date, the enhanced component applied to heavy oil pools has been limited to waterflood and some thermal projects. The estimates for the reservoir properties and other engineering parameters are based on the assumption that similar size pools in the same geological play would exhibit similar characteristics. Each undiscovered pool was assigned a recovery factor via comparison with already discovered pools through a data-matching process using information stored in the existing provincial databases.

The Board also made an estimate of the extent to which recovery factors would appreciate over time. This was made under the assumption that more efficient and economical recovery will be made possible by improved operating practices and new technologies. This future improved recovery has two components. The first includes the contribution to improved recovery through the application of commercially-proven current technologies: including primarily the use of in-fill drilling with both horizontal and vertical wells, improved production practices, and the improvement and extension of waterflood and steam injection projects. In this regard, screening criteria were applied to each undiscovered pool based on geological play, expected oil type, lithology and other reservoir parameters, as described in Bowers and Drummond, 1997[1]. The second component is more speculative and refers to the potential contribution of technologies still not commercially-proven in conventional heavy oil pools. These could include steam-assisted-gravity-drainage (SAGD), vapour-extraction (VAPEX), as well as future technologies at various stages of research and those that may not be conceived yet.

3.3 Supply Cost Evaluation – Overview

The Board conducted an economic analysis of both the remaining recoverable oil volumes of the discovered pools and the estimated recoverable oil volumes of the undiscovered pools, based on upstream supply costs. The supply cost analysis is a financial calculation involving economic assumptions including discount rates, net present values, project risk and time. Supply cost is defined as the average cost per unit of production over the project life, and includes a 10 percent after-tax rate of return to the producer. It includes capital costs associated with exploration, development and production, fixed and variable operating costs, royalties and taxes. Transportation costs to the markets are not included. The supply costs were calculated using Merak's Canadian Petroleum Economic Evaluation Program (PEEP) model. The supply cost analysis establishes the threshold size that a single well pool must be in order to be developed economically.

3.4 Geological Data Analysis

3.4.1 Input Data

The oil-in-place data used in the Board's assessment was obtained from the respective provincial governments' reserves databases. There are three categories of data: designated pools, Alberta potential pools, and Saskatchewan miscellaneous pools.

The designated pool information is the reserves information specific to each discovered and identified pool. In most cases, the database provided the field name, pool name, original oil in place, primary recovery factor, enhanced recovery factor, total recovery factor, primary reserves, enhanced reserves, total reserves, cumulative production (to year-end 1997 or 1998), remaining reserves, pool area, net pay, porosity, water saturation, formation volume or shrinkage factor, specific gravity, depth and discovery year.

In cases where there were commingled pools, the pool information was subdivided to the individual pool component level and each component pool was counted in its respective play. For example, if there was a commingled Rundle and Cretaceous pool, the portion of oil in place belonging to the Rundle zone was counted as one pool in its proper Rundle play and the Cretaceous portion was counted as one pool in its proper Cretaceous play. The proportion assigned to each pool was taken from the provincial databases or calculated by comparing the respective size of each component pool with the total size of the commingled pool. For Saskatchewan, the unit and non-unit portions of pools were combined and the combined data entered as a single pool in its proper play. In cases where the provincial government designated a pool to the general Blairmore or Mannville Group, the NEB reviewed the geological information in order to assign the pool to the appropriate stratigraphic interval. The decision on whether to assign a pool as light or heavy was dependent upon the respective provincial government agency. As it defines heavy oil, the NEB includes those pools designated as heavy in British Columbia or Alberta, and those pools designated as medium or heavy in Saskatchewan. All Manitoba pools were considered to be light oil regardless of the specific gravity.

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[1] Bowers, B., and Drummond, K.J., 1997, *Conventional Crude Oil Resources of the Western Canada Sedimentary Basin*; Journal of Canadian Petroleum Technology, Volume 36, No. 2, February, 1997.

Information on potential pools in Alberta was accessible to the NEB through the Common Reserves Database Agreement between the Alberta Energy and Utilities Board (EUB) and the NEB. This information was prepared by the EUB and NEB as part of an internal evaluation process that is completed on all wells in the province. Evaluators have the option of identifying zones as having potential resources of light oil, heavy oil, bitumen or natural gas. The information includes the field name, well location, zone name, depth, net pay, porosity, water saturation and drill date. In this study, the NEB provided a nominal area assignment to each potential discovery and a shrinkage factor representative for that zone in that area of the province. The area assignment was generally one-half of the province's minimum assignment for that zone in that area. From this information, the NEB calculated a potential oil-in-place volume for each potential pool. While this calculated potential volume was counted as a discovered pool in the modelling process, it had to be added to the generated undiscovered potential total and removed from the discovered volume total because the potential pools are still not developed and confirmed pools. These potential pools helped to better define the actual pool distribution of a particular play.

The Saskatchewan Department of Energy and Mines (SEM) miscellaneous reserves information raised more complex issues. For many of the geological formations, in each of its Production and Disposition Areas, and for different oil types, the SEM carries a miscellaneous reserves listing. This listing includes the same reserves information as noted in the designated pool information. The listing is dynamic, and the volume of reserves carried is capable of changing by a significant amount, positively or negatively, each year depending on events. The reserves represent a compilation of data from a number of single well pools, abandoned wells and pools that are waiting on full designation by the SEM. In order to account for these volumes, the NEB determined the number of producing wells for each zone in Saskatchewan that were not assigned to designated oil pools. These wells were then grouped on a geographical basis, such that if two wells were located within a section of each other, they were considered to comprise a single pool. These grouped pools were then assigned an in-place volume assuming normal distribution. The sum of the in-place volumes assigned to all the grouped pools in a zone equalled the in-place volume assigned to that miscellaneous category by the SEM.

3.4.2 Geological Modelling

The GSC initially entered only the data for the designated heavy oil pools (oil in place and discovery date) into its PETRIMES discovery process model. The output results obtained from PETRIMES were considered to be statistically suspect by the GSC. Discussion as to why the results were suspect centred on two areas: input data and discovery history.

Inputting only the heavy oil data may skew the data for particular plays since the definition of heavy oil changes across provincial boundaries. In addition, classifications may change from time to time depending on marketing and transportation considerations, and this may have some impact as well.

The discovery history of heavy oil has been sporadic in nature in the WCSB. Industry activity levels respond to the profitability of producing heavy oil, which can be seriously affected both by the price of crude oil and the relative price differential between light and heavy crude oil. When heavy oil production is profitable, industry responds by drilling a large number of wells. The PETRIMES model is partly dependent on the timing of discoveries, since one of its assumptions is that the larger pools tend to be found early in the development history. The boom and bust cycles of heavy oil development may impact that assumption since exploration may be delayed by the economic cycles.

The GSC then recommended the use of its geo-anchored discovery process model. This model does not make assumptions on the shape of the pool size distribution, but does assume that the probability of discovering a pool is proportional to the size of the pool. This method generally predicts the resources contained within the interval of the largest and smallest discovered pools. The geo-anchored method is a variation of the Arps-Roberts methodology, which was originally developed for the Denver Basin in Colorado. As a result, the geo-anchored model will predict a large number of undiscovered small pools when there are small pools present in the distribution. One of the advantages of this methodology is that it can handle a slight mixing of the population within a play. That mixing may result from either including pools that more properly belong to a different play or mixing of light with heavy pools. Readers are referred to papers by Kaufman, 1986[1] and Chen & Sinding-Larsen, 1999[2] which describe this methodology. A "pool" is defined as any accumulation of crude oil in the ground regardless of size, for the remainder of this report.

The second GSC run used the designated and potential pool information from both light and heavy oil pools as inputs for the geo-anchored model. The output was considered to be statistically sound by the GSC. However, a closer review of the plays in Saskatchewan revealed a new challenge. For those plays with a large miscellaneous volume, the generated undiscovered resource estimates were insufficient to account for the already discovered miscellaneous oil-in-place volumes. In order to overcome this challenge, it was necessary to include the information from the miscellaneous pools on the discovered resource side of the input data.

The final GSC run used the designated, potential and miscellaneous pool information from light and heavy oil pools (the whole play population) as inputs for the geo-anchored model. The output of these runs was sub-divided into separate light and heavy oil populations. The heavy oil outputs used in this report are the sum of the mean values generated for each undiscovered pool in each play.

3.5 Reservoir Data Analysis

The methodology used by the Board is based on the statistical analysis of reservoir properties. The process basically consists of organizing the reservoir properties data into the groups or categories consistent with the geological play model and then using this information to apply appropriate reservoir properties to the undiscovered pools (Table 3.1).

As only oil-in-place volumes of each play were modelled in the geological model, the reservoir properties of each pool are based on the latest reserves databases from the provincial agencies. Oil recovery factors and reservoir parameters, ordered by crude oil type and recovery mechanism,

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[1] Kaufman, G.M., 1986, *Finite Population Sampling Methods for Oil and Gas Resource Estimation.*

[2] Chen, Z. and Sinding-Larsen, 1999, *Estimating Petroleum Resources Using the Geo-Anchored Method - A Sensitivity Study*, Natural Resources Research V. 8, No. 1, p. 49-58.

TABLE 3.1

Reservoir Data Analysis Methodology

1	Construct a database using the reservoir data from the provincial databases.
2	Statistical analysis of oil recovery factors and reservoir parameters by crude oil type and recovery mechanism.
3	Separate the output results from the geological model into two groups; discovered and undiscovered pools.
4	Match reservoir information from the database in Step 1 to the corresponding discovered pools.
5	Assign reservoir properties of the discovered pools from the database in Step 1 to similar sized undiscovered pools in Step 3.
6	Eliminate the undiscovered pools in Step 5 that are smaller than the cut-off limit for future pool development from further evaluation.
7	Determine the remaining recoverable volumes for discovered pools.
8	Estimate the recoverable volumes of the remaining undiscovered pools.
9	Estimate possible additional recoverable volumes for each of the discovered and undiscovered pools based on the screening criteria for improved recovery.
10	Estimate possible additional recoverable volumes through use of new proven technology and improvements from better production practices.
11	Analyse the results of steps 6 to 9 using pool size distributions.

were statistically analysed in order to establish oil recovery factors for future discoveries from the set of undiscovered pools.

The geological model results are separated into two groups – the discovered and undiscovered pools. The discovered pools are matched with the corresponding reservoir information from the provincial databases, and appropriate reservoir information of similar sized pools is assigned to corresponding undiscovered pools. Pools having an oil-in-place volume larger than the minimum cut-off are included for further evaluation.

Future production will come from the recoverable resources in both the discovered pools and undiscovered pools. This future production includes the volumes from improved recovery, which has two components. The first includes the contribution from the application of commercially-proven current technologies. This includes primarily the use of in-fill drilling with both horizontal and vertical wells, optimized production practices, and the improvement and extension of waterflood and steam injection projects. In this regard, screening criteria were applied to each undiscovered pool based on the geological play, the expected oil type, lithology and other reservoir parameters as described in Bowers and Drummond, 1997. The second component of future improved recovery is more speculative and refers to the potential contribution of technologies still not commercially-proven in conventional heavy oil pools, such as steam-assisted-gravity-drainage (SAGD), vapour-extraction (VAPEX), and future technologies that may not be conceived yet. The respective potential of these components was assessed using the reservoir and production data, enhanced recovery selection criteria and statistically established recovery factor guidelines. The results are further analysed to determine the effects of pool size distributions.

3.6 Consultation Process – Overview

The Board used the results of the geological and engineering evaluations to establish preliminary estimates of the undiscovered resources and also to do a preliminary assessment of recoverable volumes, based on currently available technology and production practices. Subsequently, relevant provincial government agencies, petroleum research organizations, and active exploration and producing oil companies were asked to comment on the Board's resource estimates. After considering information from all parties, the Board finalized its estimates, including estimates of future improved recovery.

3.7 Supply Cost Evaluation

The analysis of the economics of conventional heavy oil exploration and development made extensive use of the wealth of available general well information and production data. Statistical and graphical analyses of this data were used to generate average or typical well production profiles, organized by geological play and by well recovery category, which were used in turn to generate supply cost curves (Table 3.2).

3.7.1 Typical Well Profile

Most of the production analysed was based on primary production, or cold heavy oil production, practices. The problems associated with heavy oil production include frequent equipment failures, wellbore problems, saltwater disposal and sand disposal. In recent years, technological innovations (including innovative completion techniques, pumping optimization, surface monitoring and control systems) developed to handle these problems have made significant contributions in reducing the supply costs of conventional heavy oil.

A large amount of production data was reviewed to assure the quality of the inputs used. Although each well has a degree of unique production characteristics, most wells display a similar exponential depletion pattern, when production rate is plotted versus time (Figure 3.1). Curves representing cumulative production versus time also exhibit similar patterns for different wells. In general, wells have a life span of less than 10 years. More than 50 percent of the cumulative volume is recovered within two years of startup and approximately 80 percent is recovered within

TABLE 3.2

Supply Cost Evaluation Methodology

1	Evaluate performance of individual sampled wells to establish typical well profiles. Performance factors considered were: monthly rates, oil cuts, water cuts, and cumulative production.
2	Establish production profile for typical wells with different categories of production rates.
3	Within each geological play, establish the distribution profile for each well recovery category.
4	Establish cumulative frequency distributions for each play type.
5	Calculate supply cost for each well recovery category.
6	Calculate supply cost for each geological play.
7	Establish supply cost curve for each geological zone.
8	Establish aggregate supply cost curve for conventional heavy oil.

four years. The parameters for a typical well profile (Figure 3.2) were established based on the common depletion patterns described above. The typical well production profiles were used to generate monthly oil and water production rates for input into the supply cost calculations. The supply cost also included an assumption of two percent sand production.

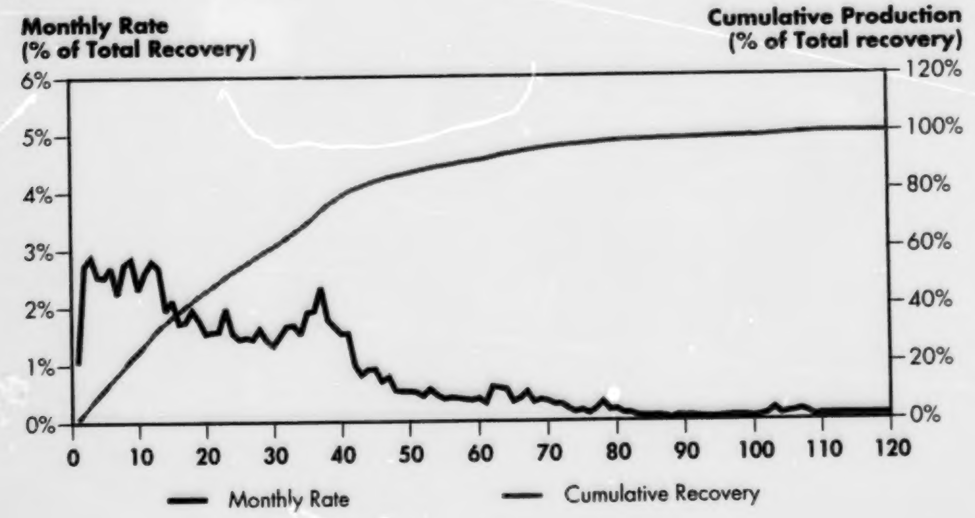
3.8 Data Presentation

In subsequent chapters, the input data, output summary, and analysis is provided in the following format for each play:

- A map, indicating the geographical location and outlining any relevant geological information.
- A datasheet (using a format designed by the Canadian Gas Potential Committee), presenting the discovered and undiscovered resource information, the minimum, maximum and average values for the primary reservoir parameters, and individual pool information for the larger discovered pools and largest 40 undiscovered pools. Note, the recoverable volumes on the datasheets only reflect the portion that can be recovered using current technology and production practices.
- A summary table, with the input and output data totals and a breakdown of the undiscovered pool sizes and total undiscovered resource estimates for each size class (Note that this summary table has not been corrected for potential pools).
- A pool-rank plot, showing the distribution of the largest 50, 100 or 200 pools in a particular play, depending on the number of pools projected for that play. This plot will illustrate where the largest missing or undiscovered pools are likely to be found in comparison with the largest discovered pools. Readers who wish to see the full distribution can create the plot using the input and output data available from the Board's website.
- A cross plot, which displays the net pay and area of discovered pools as a function of pool size. This cross plot is used to provide a general indication of the net pay and area characteristics that an undiscovered pool of a given pool size could exhibit. It is

FIGURE 3.1

Typical Well Performance

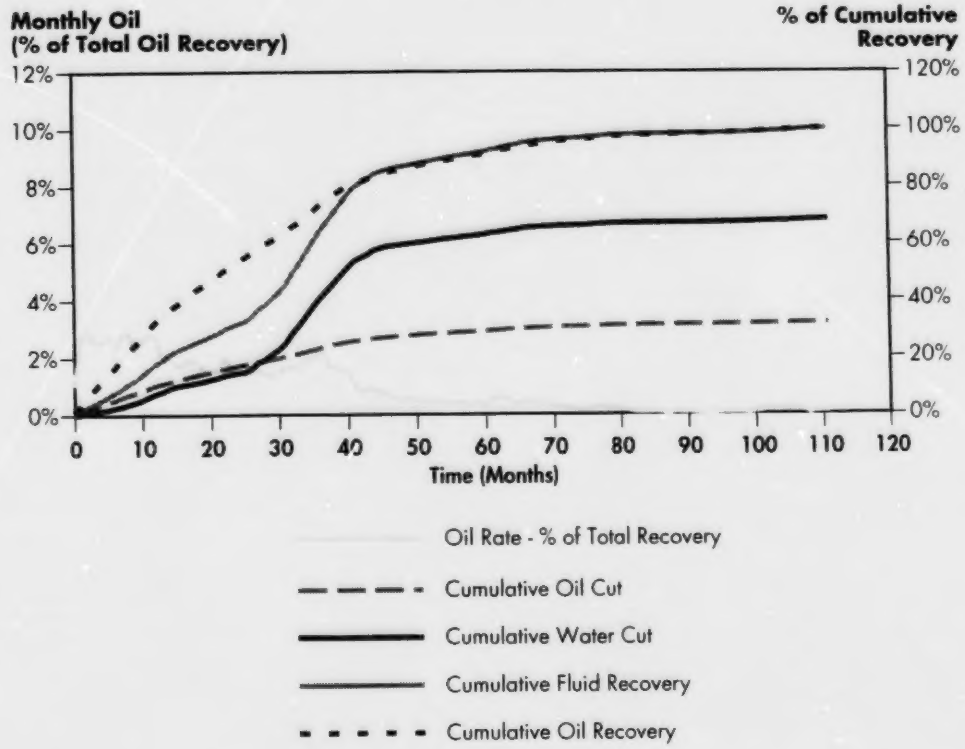


extremely unlikely that a newly-discovered pool will exactly match either the projected area or net pay. This cross plot is meant to be a reference check to the projected pool size.

- The Board has made available on its Web site (www.neb-one.gc.ca) the data output files received from the GSC. They can be accessed through the electronic version of this report on the Board's Web site under Energy Overview, Assessment (Energy Resources). This file provides the input data, the output data including the range of values for each undiscovered pool, and the resources totals for the discovered and undiscovered pools (Note that this output file has not been corrected for potential pools).

FIGURE 3.2

Typical Well Profile



4. Carboniferous Zone Play Results

4.1 Geological Overview[1]

In the WCSB, there were two main depositional areas during Carboniferous time – the Peace River Embayment in northwestern Alberta, and the Williston Basin which extended from southeastern Alberta to southwestern Manitoba in Canada. The area between, the Alberta Shelf, was occupied by a shallow-water shelf. The depositional areas were reduced in size over time as the shelf expanded. Deposition on the shelf was periodically interrupted by surface exposure and subsequent erosion.

The Carboniferous section was subdivided on the basis of lithotype and depositional history into lower, middle and upper units. The lower unit consists of deposits from two shallowing-upwards sequences representing transgressive to regressive events. The middle unit consists of deposits from multiple transgressive to regressive events. In general, the deposits on the shelf areas begin with high energy bioclastic grainstones, while the basinal areas grade from shales through to evaporites. In the Williston Basin region, the shelf deposits prograde over and intertongue with slope deposits. In the Peace River Embayment region, the shelf deposits overlie the Banff Formation or intertongue with the slope deposits of the Prophet Formation further to the west.

Light and heavy oil occurrences in these plays are trapped below unconformities at the northeast truncation of shelf carbonate deposits and in outliers. Reservoir rocks are generally dolomitized grainstones and packstones. Seals are provided by continental and marine rocks both vertically and laterally, or by cementation at the unconformity boundary. For pools downdip from the subcrop edge, seals are provided by the tidal carbonates or evaporites that cap each transgressive-regressive cycle. The heavy oil zones in this chapter are found in the lower and middle units which are present across the Alberta Shelf and the Williston Basin.

4.2 Alberta Shelf Region

The Alberta Shelf Region extends from southeastern Alberta to northeastern British Columbia and into the Northwest Territories, but excludes the Peace River Arch Region that contains only light oil plays. The heavy oil plays included in this region are the Rundle – Sweetgrass Arch and Mississippian Subcrop plays.

4.2.1 Rundle – Sweetgrass Arch Play

This play includes all pools in the Rundle Group carbonates, found in structural and structural-stratigraphic combination traps. The play area covers southern Alberta and the extreme

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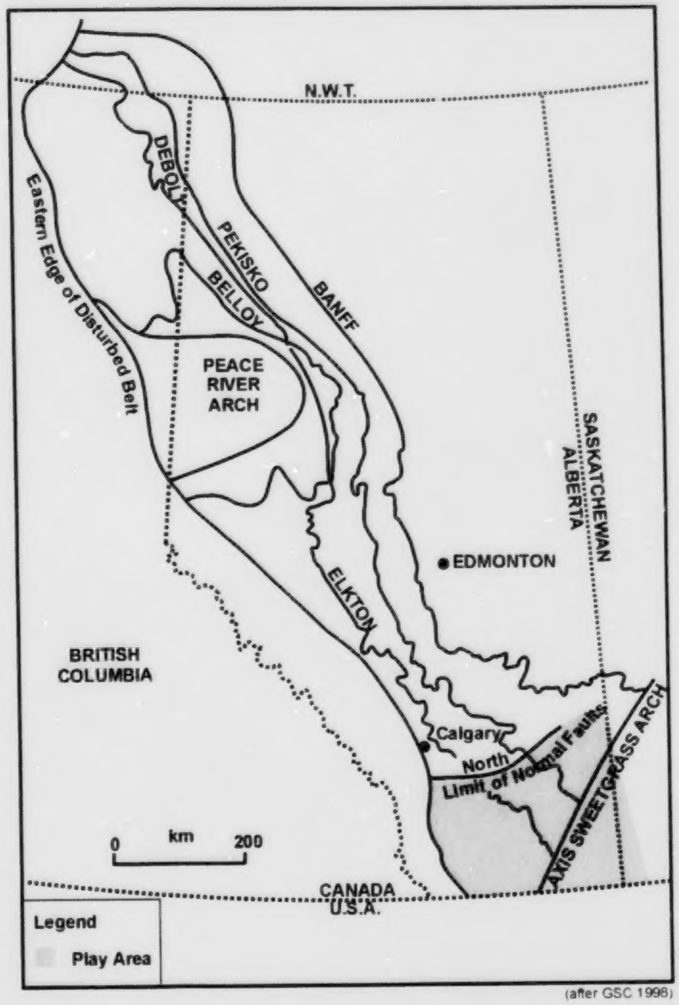
[1] This geological description and subsequent geological descriptions as well as the play descriptions are based on the descriptions provided in GSC Open File 3674.

FIGURE 4.1

Rundle – Sweetgrass Arch Play Area


N.W.T.
DEBOLT
PEKISKO
BELLOY
BANFF
Eastern Edge of Disturbed Belt
PEACE RIVER ARCH
SASKATCHEWAN
ALBERTA
EDMONTON
ELKTON
BRITISH COLUMBIA
Calgary
North Limit of Normal Faults
AXIS SWEETGRASS ARCH
0 km 200
CANADA
U.S.A.
Legend
Play Area

(after GSC 1998)

southwestern part of Saskatchewan (Figure 4.1). It extends from the Foothills disturbed belt eastwards over the Sweetgrass Arch and northwards to the limit of normal faults and the subcrop edge of the Pekisko Formation. The source rocks for the oil in these pools are believed to be Bakken and Exshaw shales. The majority of the discovered pools contain heavy oil.

The Board's assessment is based on a discovered oil-in-place estimate of 11.2 million m^3, contained in 55 designated pools (Table 4.1). This was supplemented by the addition of 18 identified potential pools, containing 0.8 million m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model (Table 4.2). There were no identified miscellaneous pools for this play. The model projects an additional 484 undiscovered pools exist. They are expected to contain 23.3 million m^3 of oil in place. The projected pools include 54 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture about half of the total undiscovered potential. The total resource estimate is 35.3 million m^3, of which 68 percent was undiscovered at year-end 1998.

The largest undiscovered pool should be the second ranked pool in the play at 1.1 million m^3 oil in place, behind only the Princess Pekisko A pool at 1.7 million m^3 oil in place (Figure 4.2). The cross plot information suggests that the largest undiscovered pool would occupy almost 100 ha with an average net pay of about 10 metres (Figure 4.3). Industry indicated that the undiscovered potential was too high. The Board is of the view that the application of economic criteria will reduce the developable potential to a more acceptable volume.

Based on historical production information, 60 percent of the total wells in this play produced less than five thousand m^3 each and 80 percent of the total wells produced less than 10 thousand m^3 each. Those lower production wells captured only 35 percent of the total production.

TABLE 4.1

Rundle Zone – Heavy, Sweetgrass Arch, Southern Alberta and Saskatchewan

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
55	11,218	1,111	865	345	502	24,089	1,662	557	35,307	2,872	2,007

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
			Ave	Min	Max	Ave	Min	Max	1966
Alberta	831								
Saskatchewan	380		1047	880	1720	6.8	1.1	23.8	
Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	68
0.12	0.05	0.3	51.2	8	544	0.62	0.25	0.85	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (103m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	PRINCESS	PEKISKO A	19470805	1712.0	1	2	1072	1072	4
3	RANGEVIEW EAST (SK)	MADISON	19941211	816.7	2	7	581	1653	7
4	RANGEVIEW (SK)	MADISON	19940216	809.6	3	9	479	2132	9
5	BATTLE CREEK (SK)	MADISON	19660813	792.6	4	11	407	2539	11
6	BANTRY	PEKISKO G	19721122	620.0	5	13	357	2896	12
8	TABER SOUTH	TURNER VALLEY A	19860510	505.0	6	15	324	3220	13
10	SUFFIELD	PEKISKO A	19880607	431.0	7	17	299	3519	15
12	BANTRY	PEKISKO L	19780000	360.0	8	19	278	3797	16
14	HAYS	LIVINGSTONE A	19960210	325.0	9	21	258	4055	17
16	Little Bow (potl)		19810823	308.7	10	22	249	4304	18
18	BANTRY	PEKISKO I	19830315	303.0	11	24	231	4535	19
20	BROOKS	PEKISKO A	19960209	268.0	12	25	224	4759	20
23	JENNER	PEKISKO G	19910124	234.0	13	26	211	4970	21
27	DIVIDE (SK)	MADISON	19951026	208.3	14	28	201	5171	21
30	JENNER	PEKISKO M	19901212	196.0	15	29	196	5367	22
32	ATLEE-BUFFALO	BANFF A	19820108	188.0	16	31	190	5557	23
33	PRINCESS	PEKISKO G	19910803	187.0	17	34	184	5741	24
38	JENNER	PEKISKO F	19861213	174.0	18	35	182	5923	25
40	BANTRY	PEKISKO B	19760728	172.0	19	36	179	6102	25
42	BANTRY	PEKISKO K	19840306	168.0	20	37	175	6277	26
46	BANTRY	PEKISKO N	19800917	160.0	21	39	173	6450	27
51	PRINCESS	PEKISKO J	19920127	150.0	22	41	169	6619	27
52	JENNER	PEKISKO I	19870811	149.0	23	43	167	6786	28
58	PRINCESS	PEKISKO L	19940518	140.0	24	44	163	6949	29
59	TABER SOUTH	LIVINGSTONE A	19920219	139.0	25	45	162	7111	30
63	JENNER	PEKISKO B	19660817	134.0	26	47	158	7269	30
66	PRINCESS	PEKISKO K	19450705	131.0	27	48	156	7425	31
70	JENNER	PEKISKO D	19710319	124.0	28	49	154	7579	31
73	BANTRY	PEKISKO J	19821219	120.0	29	50	151	7730	32
75	Red Coulee (potl)		19950821	118.2	30	53	148	7878	33
					31	54	146	8024	33
					32	55	145	8169	34
					33	56	143	8312	35
					34	57	140	8452	35
					35	60	138	8590	36
					36	61	137	8727	36
					37	62	135	8862	37
					38	64	133	8995	37
					39	65	131	9126	38
					40	67	129	9255	38

Approximately 55 percent of the total production was produced by the 18 percent of wells that produced 10 to 20 thousand m^3 each. The supply costs determined for a typical well in this play are estimated to be \$80-\$92/m^3, the third highest in the Carboniferous Zone (Supply costs are discussed in Chapter 7).

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 16.8 to 25.3 million m^3, largely due to new discoveries. There were 20 new pools found between year-end 1994 and year-end 1998.

TABLE 4.2

Rundle Sweetgrass Arch Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^3m^3)	Number of Pools	OIP (10^3m^3)
10 - 100 million	0	0	0	0
1 - 10 million	1	1712	1	1072
100 - 1000 thousand	29	8432	53	9775
10 - 100 thousand	41	1891	380	12044
<10 thousand	2	14	50	367
Total	**73**	**12049**	**484**	**23258**

FIGURE 4.2

Pool Rank Plot – Rundle Sweetgrass

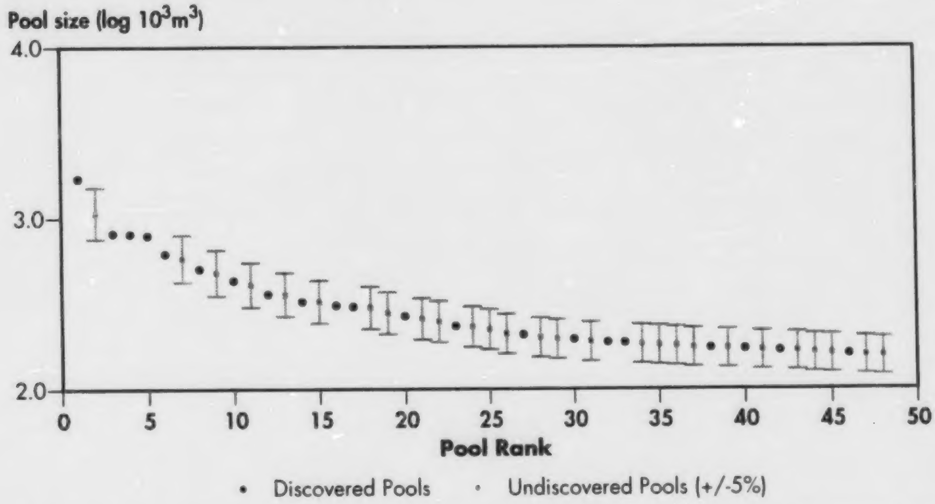
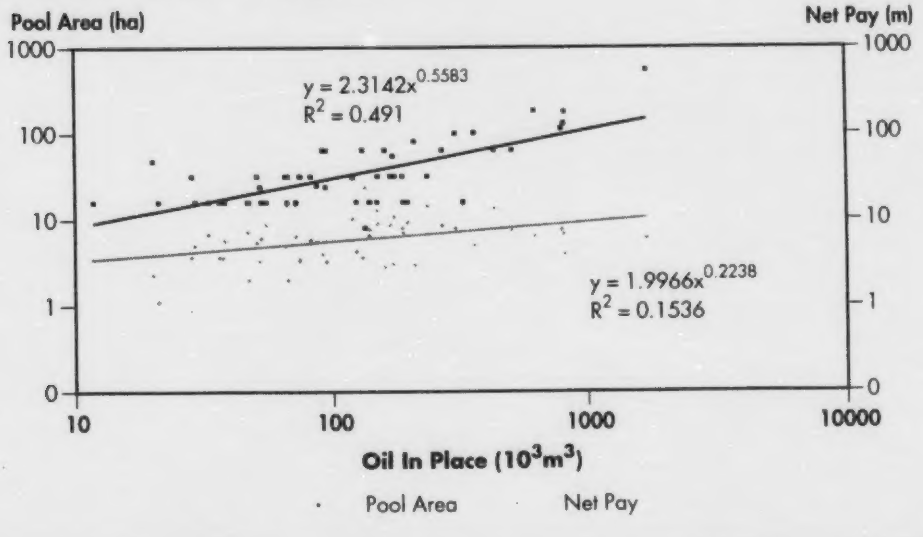


FIGURE 4.3

Cross Plot – Rundle Sweetgrass

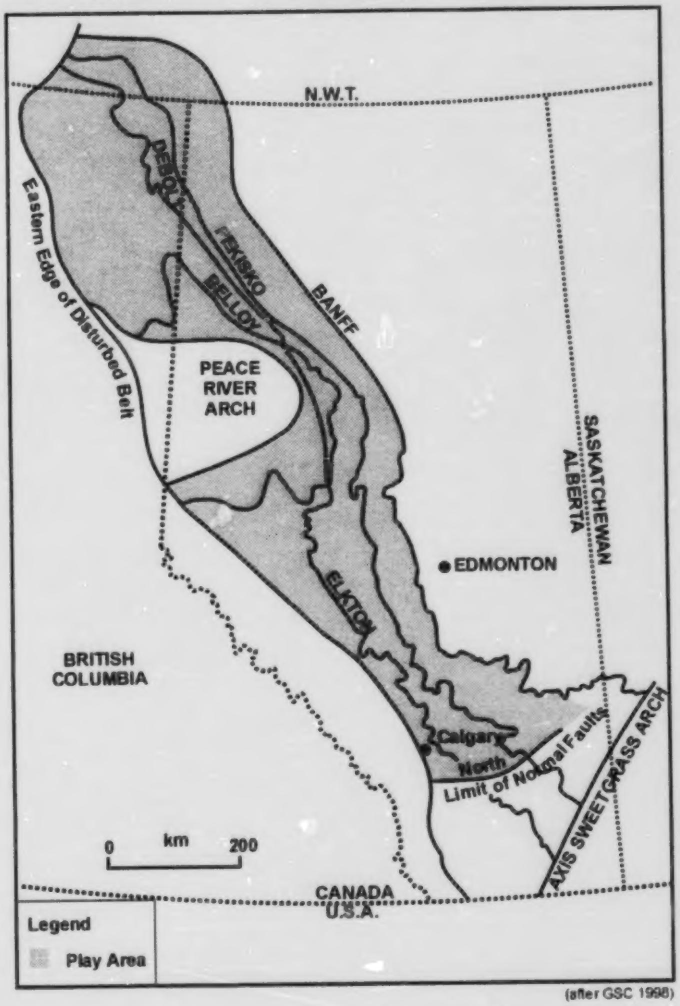


4.2.2 *Mississippian Subcrop Play*

This play is defined to include all the oil pools found in unconformity traps at the subcrop edges of the Banff, Pekisko, Shunda, Elkton, and Debolt Formations. It extends from the northern limit of the Rundle Sweetgrass Arch play in southern Alberta and southwestern Saskatchewan to the southern portion of the Northwest Territories (Figure 4.4). It includes pools in the carbonate deposits along the main subcrop edge and in erosional outliers that are located in front of the main edge. The Peace River Region is excluded from this play. In this play, heavy oil makes up only 20 percent of the discovered oil-in-place volume, and the majority of heavy oil pools are found in the Banff and Pekisko Formations.

FIGURE 4.4

Mississippian Subcrop Play Area



(after GSC 1998)

Each formation has a separate seal configuration and may have separate source rocks for the oil contained therein. The Banff Formation pools are sealed by tight Banff limestones either laterally or vertically and/or by overlying shales. Oil was sourced from the Exshaw, Banff or younger shales. The Pekisko Formation has lateral trapping by younger shales or by tight carbonates, and vertical trapping by younger shales and siltstones. Source rocks are believed to be younger Jurassic and Cretaceous shales. Similarly, the Elkton and Debolt Formation traps are formed by tight carbonates or younger shales. Source rocks are believed to be younger shales. The Debolt Formation generally requires natural fracturing to have enough porosity and permeability for economic pools.

The Board's assessment is based on a discovered oil-in-place estimate of 58.4 million m^3, contained in 70 designated pools (Table 4.3). This was supplemented by the addition of 42 identified potential pools, containing 1.9 million m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model (Table 4.4). There were no identified miscellaneous pools for this play. The model projects an additional 1,238 undiscovered pools exist. They are expected to contain 162.5 million m^3 of oil in place. The projected pools include 277 pools that

TABLE 4.3

Mississippian Subcrop – Heavy, NE B.C. to Southern Alberta

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
70	58,424	5,889	4,421	1,468	1323	164,445	10,095	1393	222,869	15,985	11,564

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)	
Alberta	5424
Saskatchewan	93
British Columbia	313

	Ave	Min	Max
Depth from KB (metres)	1335	631	2382
Net Pay (metres)	6.5	1	25.5
Porosity (fraction)	0.13	0.04	0.3
Area (ha)	214	8	3380
Oil Saturation (fraction)	0.66	0.45	0.91

Discovery Yr	% Undiscovered
1948	74

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	CHERHILL	BANFF F	19810718	12250.0	1	2	9908	9908	6
4	DESAN - BC	PEKISKO	19840106	6529.3	2	3	8290	18198	11
5	ALEXIS	BANFF A	19680330	6495.0	3	6	6190	24388	15
9	BIGORAY	PEKISKO A	19620119	5274.0	4	7	5848	30236	18
10	GLENEVIS	BANFF	19510716	5005.0	5	8	5539	35775	22
14	CHERHILL	BANFF C	19690617	3558.0	6	11	4917	40692	25
17	ST ANNE	BANFF K	19900111	2682.0	7	12	4258	44950	27
23	ST ANNE	BANFF C	19810314	1572.0	8	13	3919	48869	30
24	DESAN - BC	SHUNDA A	19830116	1535.9	9	15	3292	52161	32
27	MEDICINE RIVER	ELKTON-SHUNDA B	19731210	1352.0	10	16	2999	55160	34
31	GREENCOURT	PEKISKO A	19610101	915	11	18	2484	57644	35
35	DESAN - BC	SHUNDA E	19840121	911.7	12	19	2266	59910	36
39	TURIN	LIVINGSTONE C	19860401	787.0	13	20	2078	61988	38
42	TOOGA - BC	DEBOLT A	19840203	711.6	14	21	1762	63750	39
48	GILBY	RUNDLE K	19710619	627.0	15	22	1651	65401	40
53	MATZIWIN	PEKISKO A	19620717	569.0	16	25	1479	66880	41
58	ST ANNE	BANFF A	19780614	488.0	17	26	1409	68289	42
68	BARRHEAD	BANFF A	19981112	390.0	18	28	1345	69634	42
					19	29	1217	70851	43
					20	30	1157	72008	44
					21	32	1000	73008	44
					22	33	957	73965	45
					23	34	918	74883	46
					24	36	883	75766	46
					25	37	821	76587	47
					26	38	796	77383	47
					27	40	772	78155	48
					28	41	749	78904	48
					29	43	710	79614	48
					30	44	694	80308	49
					31	45	677	80985	49
					32	46	660	81645	50
					33	47	645	82290	50
					34	49	614	82904	50
					35	50	598	83502	51
					36	51	585	84087	51
					37	52	571	84658	51
					38	54	545	85203	52
					39	55	531	85734	52
					40	56	518	86252	52

are expected to contain more than 100 thousand m^3 of oil in place each, these capture about 80 percent of the total undiscovered potential. The total resource estimate is 222.9 million m^3, of which 74 percent was undiscovered at year-end 1998.

The largest undiscovered pool should be the second ranked pool in this play at 9.9 million m^3 of oil in place, behind only the Cherhill Banff F pool which contains 12.3 million m^3 of oil in place (Figure 4.5). The cross plot information suggest that the largest undiscovered pool would occupy 1,000 ha with an average net pay of about 11 metres (Figure 4.6). Industry indicated that the total resource potential was too high. The Board believes the amount of undrilled areas, especially in

TABLE 4.4

Mississippian Subcrop Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^{3}m^3)	Number of Pools	OIP (10^{3}m^3)
10 - 100 million	1	12250	0	0
1 - 10 million	10	35120	21	73009
100 - 1000 thousand	40	10428	256	56827
10 - 100 thousand	54	2524	765	31588
<10 thousand	7	40	196	1083
Total	**112**	**60362**	**1238**	**162507**

FIGURE 4.5

Pool Rank Plot – Mississippian Subcrop

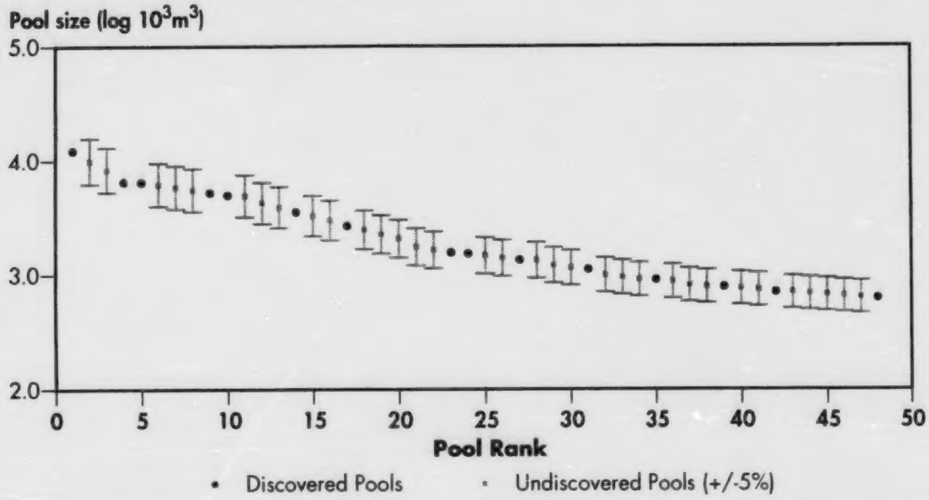
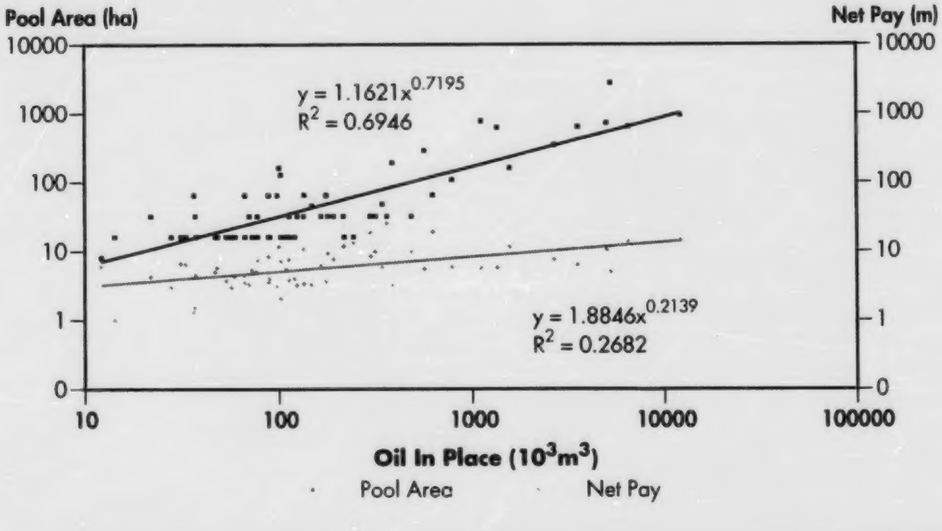


FIGURE 4.6

Cross Plot – Mississippian Subcrop



the northern part of Alberta, justifies the potential estimate. The application of economic criteria will reduce the developable potential. A phenomena observed on most of the cross plots is a series of pools having the same area, for example at 16 and 32 ha. These represent pools where the respective provincial agency has assigned an area in its reserves calculation.

The cumulative distribution of wells in this play is similar to that of the Rundle-Sweetgrass play. In this case, 66 percent of the wells produced less than five thousand m^3 each and 80 percent of the wells produced less than 10 thousand m^3 each. These wells produced only 37 percent of the total production from this play. Approximately 50 percent of the total production was captured by wells that produced between 10 and 20 thousand m^3. The supply costs for this play are the second highest of all Carboniferous plays and are estimated to be in the range of $85-$98/m^3.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 447.6 to 475.3 million m^3 largely due to new discoveries. There were 47 new pools found between year-end 1994 and year-end 1998.

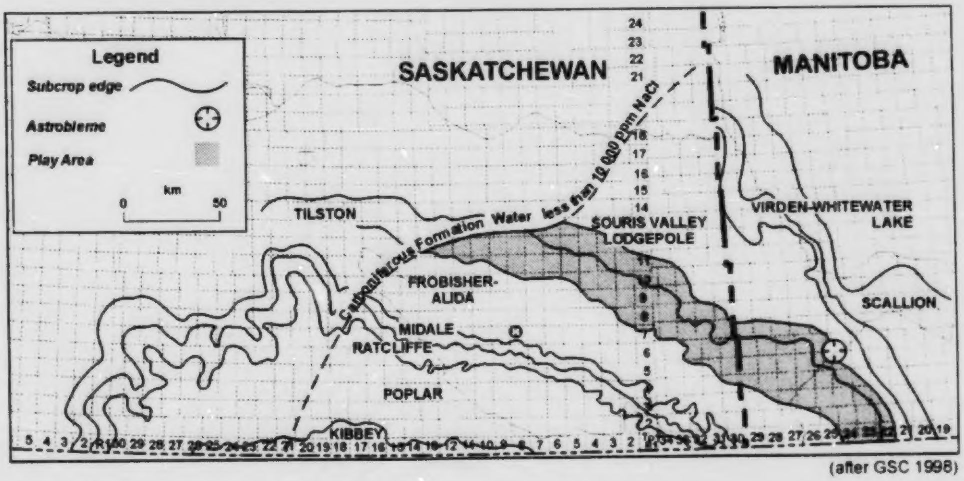
4.3 Williston Basin Region

4.3.1 Souris Valley-Tilston Play

This play is defined to include pools in the Souris Valley Beds of the Lodgepole Formation and the Tilston Beds of the Mission Canyon Formation in southeastern Saskatchewan and southwestern Manitoba (Figure 4.7). Pools in southwestern Manitoba contain similar quality crude oil to those in Saskatchewan, but are classified as light oil due to market logistics. The play area is bounded by the subcrop edge to the north and east, the international border to the south and by the zone of low salinity formation waters to the west. These carbonate units are equivalent to the Banff Formation in Alberta and overlie the organic-rich Bakken shale. Top seal is provided by the impermeable Watrous Formation, by porosity pinchout within the Souris Valley and Tilston Beds, or by the subcrop edge. The source is believed to be either the Bakken shale or the Madison Group carbonates. Only 30 percent of all pools in this play contain heavy oil.

FIGURE 4.7

Souris-Tilston Play Area


Legend
Subcrop edge
Astrobleme
Play Area
km
0
50
SASKATCHEWAN
MANITOBA
TILSTON
Carboniferous Formation Water less than 10 000 ppm NaCl
SOURIS VALLEY
LODGEPOLE
VIRDEN-WHITEWATER LAKE
FROBISHER-ALIDA
MIDALE
RATCLIFFE
POPLAR
KIBBEY
SCALLION
24
23
22
21
18
17
16
15
14
6
5

(after GSC 1998)

The Board's assessment is based on a discovered oil-in-place estimate of 48.5 million m^3 found in 29 discovered pools (Table 4.5). These discovered pools consist of eight designated pools containing 26.7 million m^3 and 21 assigned miscellaneous pools containing 21.7 million m^3, almost as much oil as found in the designated pools. There are no potential pools for this play. The model projects an additional 186 undiscovered pools exist. They are expected to contain 28.1 million m^3 of oil in place (Table 4.6). The projected pools include 59 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture about 83 percent of the total undiscovered potential. The total resource estimate is 76.5 million m^3, of which 37 percent was undiscovered at year-end 1997.

TABLE 4.5

Souris-Tilston – Heavy, Southeastern Saskatchewan and Manitoba

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
29	48,465	4,512	1,966	2,833	186	28,071	1,373	215	76,536	6,172	4,206

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr
Saskatchewan	4512		Ave	Min	Max	Ave	Min	Max	1957
			1194	1149	1216	9.2	2.4	12.1	
Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	37
0.13	0.12	0.16	451	65	1165	0.6	0.6	0.6	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	Misc # 1	SV-T		10478.4	1	5	3180	3180	11
2	MOOSE VALLEY	TILSTON	19580805	8822.3	2	9	1849	5029	18
3	HAZELWOOD SOUTH	TILSTON	19930821	8665.1	3	12	1276	6305	22
4	HAZELWOOD CENTRAL	TILSTON	19630207	4178.9	4	13	1145	7450	27
6	Misc # 2	SV-T		3068.4	5	15	951	8401	30
7	BENDER CENTRAL	TILSTON	19910000	2404.6	6	16	804	9205	33
8	Misc # 3	SV-T		1900.3	7	18	747	9952	35
10	MOOSE VALLEY SOUTH	TILSTON	19920624	1367.7	8	19	655	10607	38
11	Misc # 4	SV-T		1339.8	9	21	619	11226	40
14	Misc # 5	SV-T		1005.0	10	22	562	11788	42
17	Misc # 6	SV-T		781.5	11	24	538	12326	44
20	Misc # 7	SV-T		621.9	12	26	499	12825	46
23	HAZELWOOD WEST	TILSTON	19571110	555.9	13	27	482	13307	47
25	Misc # 8	SV-T		502.4	14	29	448	13755	49
28	BENDER SOUTH	TILSTON	19911001	463.0	15	30	434	14189	51
32	Misc # 9	SV-T		409.9	16	31	419	14608	52
37	Misc # 10	SV-T		336.5	17	33	391	14999	53
43	BENDER	TILSTON	19900928	284.9	18	34	378	15377	55
					19	35	364	15741	56
					20	36	339	16080	57
					21	38	329	16409	58
					22	39	319	16728	60
					23	40	309	17037	61
					24	41	292	17329	62
					25	42	285	17614	63
					26	44	277	17891	64
					27	46	262	18153	65
					28	47	256	18409	66
					29	48	249	18658	66
					30	49	242	18900	67
					31	50	236	19136	68
					32	52	222	19358	69
					33	53	216	19574	70
					34	54	210	19784	70
					35	55	204	19988	71
					36	56	198	20186	72
					37	58	187	20373	73
					38	59	181	20554	73
					39	60	176	20730	74
					40	61	171	20901	74

The largest undiscovered pool should be the fifth ranked pool in the play at 3.2 million m^3 of oil in place, behind the Moose Valley, Hazelwood South and Hazelwood Central Tilston pools and the largest miscellaneous pool (Figure 4.8). The cross plot information suggests that the largest undiscovered pool would occupy about 600 ha with an average net pay of about nine metres (Figure 4.9). Industry indicated that the largest undiscovered pool was too small. The Board is of the view that the largest undiscovered pool fits the size projection provided by the model, but recognizes that there could be a larger undiscovered pool found in the future.

Approximately 80 percent of the wells in this play produced less than five thousand m^3 each and these wells account for 35 percent of the total production. Ninety-five percent of the wells produced less than 10 thousand m^3 each, accounting for 65 percent of the total production. None of the wells produced more than 27 thousand m^3. As a result, the supply costs of \$118-\$138/m^3 are the highest of the Carboniferous plays.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 102.4 to 134.1 million m^3 partly due to growth in existing pools, and the inclusion of the miscellaneous volumes. There were been no new pools found between year-end 1994 and year-end 1997.

TABLE 4.6

Souris-Tilston Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	**Number of Pools**	**OIP (10^{3}m^3)**	**Number of Pools**	**OIP (10^{3}m^3)**
10 - 100 million	1	10478	0	0
1 - 10 million	9	32752	4	7450
100 - 1000 thousand	13	4925	55	15906
10 - 100 thousand	6	310	127	4715
<10 thousand	0	0	0	0
Total	**29**	**48465**	**186**	**28071**

FIGURE 4.8

Pool Rank Plot – Souris-Tilston

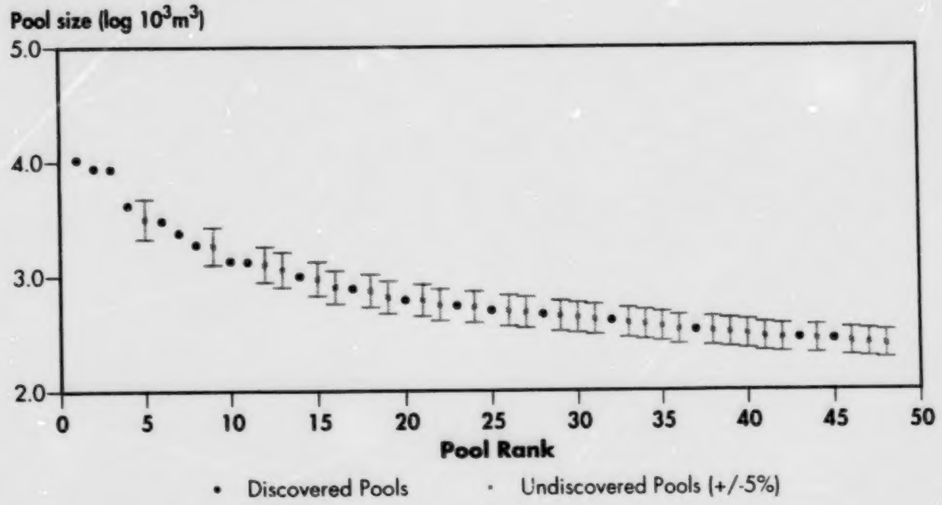


FIGURE 4.9

Cross Plot – Souris-Tilston

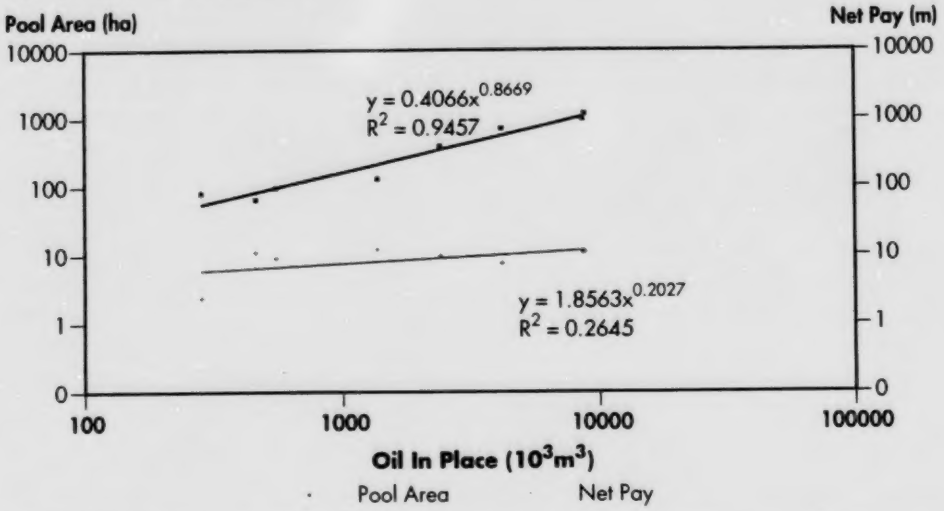
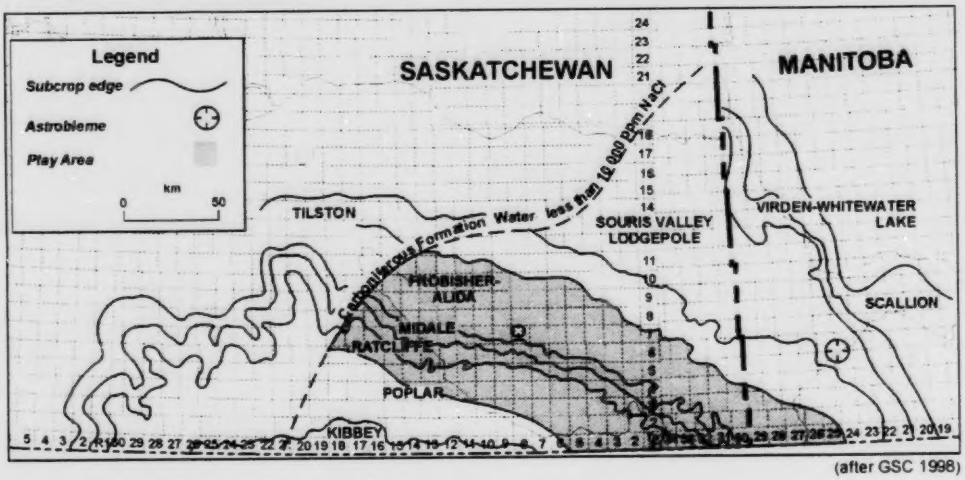


FIGURE 4.10

Frobisher-Alida Play Area


Legend
Subcrop edge
Astrobleme
Play Area
km
0
50
SASKATCHEWAN
MANITOBA
Carboniferous Formation Water less than 10 000 ppm NaCl
TILSTON
SOURIS VALLEY LODGEPOLE
VIRDEN-WHITEWATER LAKE
SCALLION
FROBISHER-ALIDA
MIDALE
RATCLIFFE
POPLAR
KIBBEY

(after GSC 1998)

4.3.2 *Frobisher-Alida Play*

This play is defined to include oil pools in the Frobisher and Alida Beds of the Mission Canyon Formation. These carbonate reservoirs consist of limestone and are trapped structurally on topographic highs related to the subcrop edge. Vertical and lateral seal is provided by tight carbonates or evaporites; while the source rock is believed to be the carbonates of the Madison Group or the Bakken shale. The play area is similar to the Souris-Tilston play although the subcrop edge is found south of the Souris-Tilston edge (Figure 4.10). Only 20 percent of all pools in this play contain heavy oil.

The Board's assessment is based on a discovered oil-in-place estimate of 108.6 million m^3 found in 118 discovered pools (Table 4.7). These discovered pools consist of 25 designated pools containing 98.2 million m^3 and 93 assigned miscellaneous pools containing 10.4 million m^3, about 10 percent of the volume found in the designated pools. There are no potential pools for this play. The model projects an additional 2,009 undiscovered pools exist. They are expected to contain 82.1 million m^3 of oil in place (Table 4.8). The projected pools include 125 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture about 71 percent of the total undiscovered potential. The total resource estimate is 190.7 million m^3, of which 43 percent was undiscovered at year-end 1997.

TABLE 4.7

Frobisher-Alida – Heavy, Southern Saskatchewan and Manitoba

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
118	108,602	20,476	15,277	5,199	2009	82,086	14,045	2127	190,688	34,521	19,244

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
			Ave	Min	Max	Ave	Min	Max	
Saskatchewan	20,476		1259	1089	1433	8.3	2.1	24.8	1953
Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	
0.11	0.07	0.19	733	32	2412	0.63	0.5	0.75	43

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (103m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	LOST HORSE HILL	FROBISHER-ALIDA	19630101	18550.6	1	4	8817	8817	11
2	INNES	FROBISHER	19650709	10673.2	2	13	2660	11477	14
3	HANDSWORTH	ALIDA	19640807	10486.1	3	15	1922	13399	16
5	HUNTOON	FROBISHER	19570108	8681.3	4	18	1763	15162	18
6	WEYBURN	FROBISHER	19560830	8544.6	5	19	1636	16798	20
7	MIDALE	CENTRAL FROBISHER	19530000	7063.1	6	20	1419	18217	22
8	INGOLDSBY	FROBISHER-ALIDA	19550614	5181.7	7	23	1375	19592	24
9	VIEWFIELD	FROBISHER	19690323	3900.7	8	24	1369	20961	26
10	FREESTONE	FROBISHER-ALIDA	19530117	3818.2	9	27	1296	22257	27
11	N. HANDSWORTH	ALIDA	19650806	3622.4	10	28	1209	23466	29
12	HEWARD	FROBISHER	19860303	3259.8	11	29	1162	24628	30
14	Misc. # 1	F-A		2602.2	12	31	1078	25706	31
16	CREELMAN	ALIDA	19680000	1821.6	13	32	1024	26730	33
17	STOUGHTON S.	FROBISHER	19741214	1812.5	14	34	954	27684	34
21	WEIR HILL	FROBISHER	19681219	1412.5	15	36	914	28598	35
22	WEST INNES	FROBISHER	19650918	1403.3	16	38	886	29484	36
25	HARTAVEN	FROBISHER-ALIDA	19650801	1350.6	17	39	827	30311	37
26	MELROSE	FROBISHER-ALIDA	19630326	1318.7	18	40	799	31110	38
30	STOUGHTON	FROBISHER-ALIDA	19601124	1113.1	19	41	771	31881	39
33	Misc. # 2	F-A		988.1	20	43	719	32600	40
35	HEWARD SOUTH	FROBISHER	19650000	928.2	21	45	687	33287	41
37	STOUGHTON N.	FROBISHER	19851210	898.5	22	47	657	33944	41
42	GRIFFIN NORTH	FROBISHER	19680416	739.1	23	48	636	34580	42
44	Misc. # 3	F-A		691.7	24	49	612	35192	43
46	SILVERTON EAST	FROBISHER	19960111	658.9	25	50	587	35779	44
52	Misc. # 4	F-A		540.4	26	51	564	36343	44
59	Misc. # 5	F-A		445.4	27	53	540	36883	45
61	BRYANT	FROBISHER	19790000	440.5	28	54	517	37400	46
62	GRIFFIN	FROBISHER	19581012	439.3	29	55	502	37902	46
69	Misc. # 6	F-A		379.2	30	56	498	38400	47
77	Misc. # 7	F-A		329.9	31	57	464	38864	47
					32	58	451	39315	48
					33	60	441	39756	48
					34	63	435	40191	49
					35	64	431	40622	49
					36	65	428	41050	50
					37	66	412	41462	51
					38	67	403	41865	51
					39	68	392	42257	51
					40	70	379	42636	52

The largest undiscovered pool in this play is expected to be the fourth ranked pool containing about 9.0 million m^3 of oil in place, behind the Lost Horse Hill, Innes and Handsworth pools (Figure 4.11). The cross plot information suggests that the largest undiscovered pool would occupy an area of 1,000 ha with an average net pay of about 10 metres (Figure 4.12). Industry indicated that the two zones should be assessed separately and that the largest undiscovered pools were too large. The Board is of the view that the two plays have been grouped based on the similar depositional and trapping styles and should remain that way. The Board supports the model's projection.

Approximately 65 percent of the wells in this play produced less than five thousand m^3 each and 80 percent of the wells produced less than 10 thousand m^3 each. Together, these wells captured only 21 percent of the total production. However, approximately 45 percent of the total production was produced by the five percent of wells that produced more than 30 thousand m^3 each. The resulting supply costs are relatively low, estimated in the range of \$61-\$70/m^3, making this a more attractive play than others.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 452.6 to 523.4 million m^3. This is due to new discoveries and the inclusion of both the Manitoba data and the miscellaneous volumes. There were five new pools found between year-end 1994 and year-end 1997.

TABLE 4.8

Frobisher-Alida Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^3m^3)	Number of Pools	OIP (10^3m^3)
10 - 100 million	3	39710	0	0
1 - 10 million	16	56906	13	26729
100 - 1000 thousand	26	9918	112	31711
10 - 100 thousand	50	1958	650	18688
<10 thousand	23	110	1234	4958
Total	**118**	**108602**	**2009**	**82086**

FIGURE 4.11

Pool Rank Plot – Frobisher-Alida

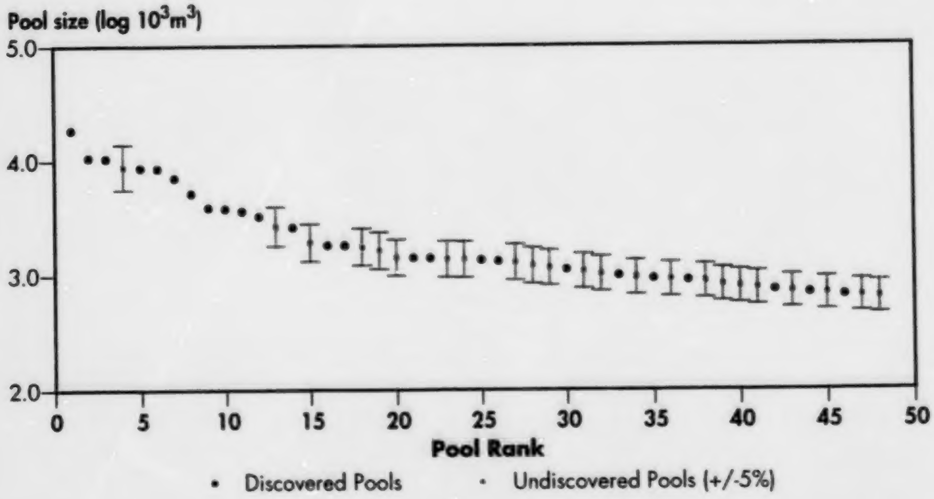


FIGURE 4.12

Cross Plot – Frobisher-Alida

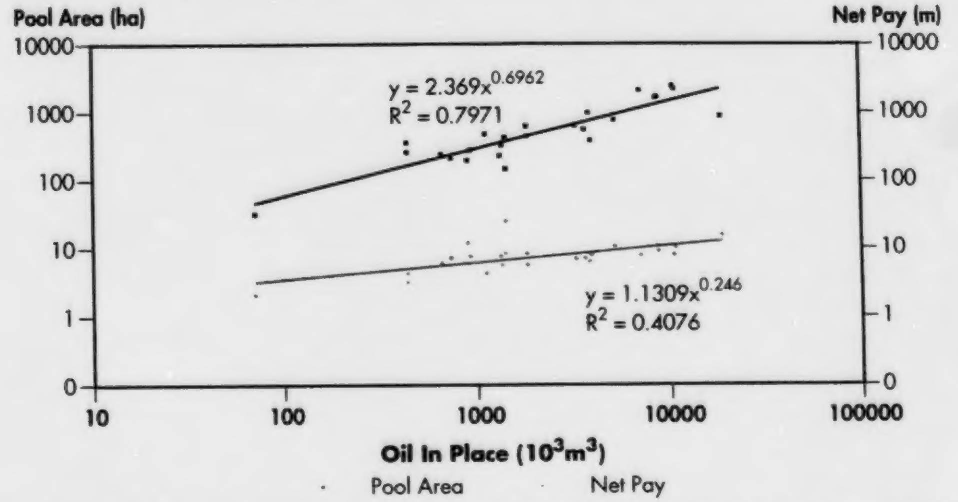
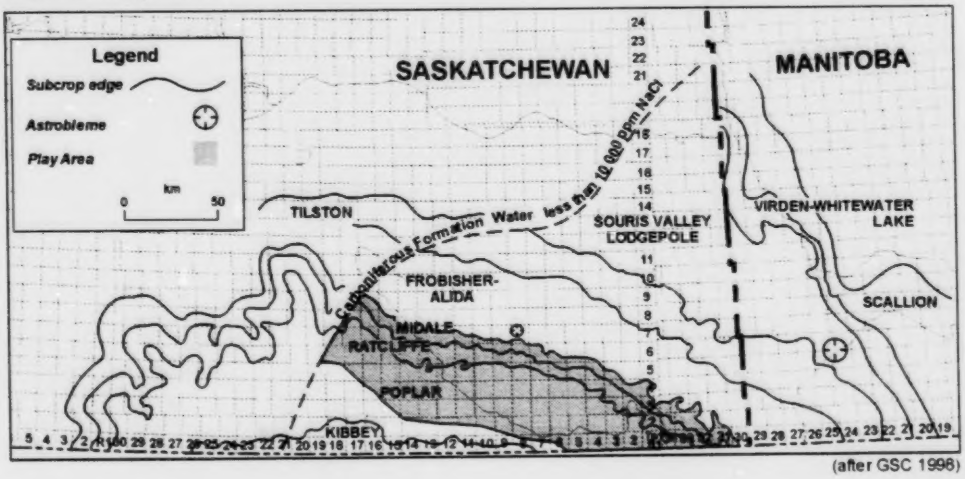


FIGURE 4.13

Midale Play Area


Legend
Subcrop edge
Astrobleme
Play Area
km
0
50
SASKATCHEWAN
MANITOBA
Carboniferous Formation Water less than 10 000 ppm NaCl
TILSTON
SOURIS VALLEY LODGEPOLE
VIRDEN-WHITEWATER LAKE
SCALLION
FROBISHER-ALIDA
MIDALE
RATCLIFFE
POPLAR
KIBBEY

(after GSC 1998)

4.3.3 *Midale Play*

This play is defined to include the heavy oil pools in the carbonate shelf and supratidal evaporite deposits in the Midale Beds of the Charles Formation. The porous portions of these beds are found between the tight Frobisher and Midale evaporites which provide lateral and vertical seals. Additional vertical seal is provided by younger shales, while source rocks are believed to be the carbonates of the Madison Group or the Bakken shale. Again, the play area is similar to the Souris-Tilston, but the subcrop edge has back-stepped from the Frobisher-Alida subcrop edge (Figure 4.13). The play is only found in Saskatchewan, and 40 percent of pools are considered to contain heavy oil. The very large Weyburn pool, which contains a mix of light and medium oil, is considered to be light for the purposes of this study. An enhanced recovery scheme, using carbon dioxide flooding to increase the recovery factor, is now in operation in that pool.

The Board's assessment is based on a discovered oil-in-place estimate of 284.9 million m³ found in 74 discovered pools (Table 4.9). These discovered pools consist of 25 designated pools containing 264.9 million m³ and 49 assigned miscellaneous pools containing 20.0 million m³, about eight percent of the volume found in the designated pools. There are no potential pools for this play. The model projects an additional 739 undiscovered pools exist. They are expected to contain 186.4 million m³ of oil in place (Table 4.10). The projected pools include 212 pools that are expected to contain more than 100 thousand m³ of oil in place each, these capture over 90 percent of the total undiscovered potential. The total resource estimate is 471.3 million m³, of which 40 percent was undiscovered at year-end 1997.

TABLE 4.9

Midale – Heavy, Southern Saskatchewan

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
74	284,920	46,300	32,006	14,294	739	186,396	21,873	813	471,316	68,173	36,167

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)		Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Saskatchewan	46,300	Ave	Min	Max	Ave	Min	Max	1953
		1467	1306	1693	8	1.7	22.5	

Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	40
0.17	0.09	0.27	1648	65	17139	0.62	0.5	0.78	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	MIDALE	MIDALE	19530424	102684.0	1	6	11238	11238	6
2	TATAGWA NORTH	MIDALE	19830901	34791.1	2	8	7877	19115	10
3	LOUGHEED	MIDALE	19590901	33020.4	3	13	5410	24525	13
4	TATAGWA CENTRAL	MIDALE	19771101	19084.2	4	14	4940	29465	16
5	BENSON	MIDALE	19560513	16942.6	5	15	4557	34022	18
7	TATAGWA WEST	MIDALE	19781205	10920.7	6	16	3779	37801	20
9	HUNTOON	MIDALE	19570130	7666.9	7	17	3744	41545	22
10	Misc. # 1			6731.0	8	20	3581	45126	24
11	ELSWICK	MIDALE	19830801	6340.9	9	22	3277	48403	26
12	NEPTUNE NORTH	MIDALE	19840205	5759.1	10	23	3143	51546	28
18	BRYANT	MIDALE	19791106	3697.1	11	25	2876	54422	29
19	ELSWICK EAST	MIDALE	19651109	3642.5	12	26	2752	57174	31
21	WEST KINGSFORD	MIDALE	19550715	3556.0	13	27	2635	59809	32
24	TATAGWA	MIDALE	19770000	2906.9	14	29	2416	62225	33
28	BROMHEAD	MIDALE	19650413	2471.8	15	31	2318	64543	35
30	Misc. # 2			2330.0	16	32	2228	66771	36
36	UNION JACK	MIDALE	19900213	1987.7	17	33	2074	68845	37
39	COLGATE	MIDALE	19830723	1909.9	18	34	2008	70853	38
43	MACOUN	MIDALE	19690530	1589.0	19	35	2006	72859	39
44	Misc. # 3			1565.6	20	37	1950	74809	40
53	Misc. # 4			1183.8	21	38	1825	76634	41
56	MINARD	MIDALE	19560000	1100.1	22	40	1766	78400	42
68	Misc. #5			948.0	23	41	1706	80106	43
69	ELLCOTT EAST	MIDALE	19940222	947.0	24	42	1650	81756	44
71	BENSON EAST	MIDALE	19830910	933.8	25	45	1538	83294	45
					26	46	1481	84775	45
					27	47	1430	86205	46
					28	48	1390	87595	47
					29	49	1379	88974	48
					30	50	1330	90304	48
					31	51	1283	91587	49
					32	52	1237	92824	50
					33	54	1160	93984	50
					34	55	1127	95111	51
					35	57	1099	96210	52
					36	58	1099	97309	52
					37	59	1073	98382	53
					38	60	1050	99432	53
					39	61	1029	100461	54
					40	62	1013	101474	54

The largest undiscovered pool is expected to be the sixth ranked pool in this play at 11.2 million m^3 of oil in place, behind the Midale, Tatagwa North, Lougheed, Tatagwa Central, and Benson pools (Figure 4.14). The cross plot information suggest that the largest undiscovered pool would occupy an area of 1,400 ha with an average net pay of nine metres (Figure 4.15). Industry indicated that the largest undiscovered pool was too large, since it is difficult to find six sections of undrilled land in that area. The Board agrees with that comment but indicates that thicker net pay would reduce the areal extent required. It may be necessary for industry to push the western and southern play limits to find this pool, or it may be that the pool has already been located by one or more of the miscellaneous wells, without the realization of the full areal extent of the larger pool. The Board supports the model's output.

Approximately 45 percent of the wells in this play produced less than five thousand m^3 each and 55 percent of the wells produced less than 10 thousand m^3 each. Together these account for only about nine percent of the total production. However, 60 percent of the total production was accounted for by wells that produced over 30 thousand m^3 each. The average supply costs are estimated in the range of \$47-\$53 /m^3, the lowest of the Carboniferous plays.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 677.8 to 715.7 million m^3 due to growth in existing pools and inclusion of the miscellaneous volumes. There were no new pools found between year-end 1994 and year-end 1997.

TABLE 4.10

Midale Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	**Number of Pools**	**OIP (10^3m^3)**	**Number of Pools**	**OIP (10^3m^3)**
10 - 100 million	6	217443	1	11238
1 - 10 million	16	54438	40	91230
100 - 1000 thousand	29	12150	171	70848
10 - 100 thousand	20	873	338	11999
<10 thousand	3	15	189	1061
Total	**74**	**284920**	**739**	**186397**

FIGURE 4.14

Pool Rank Plot – Midale

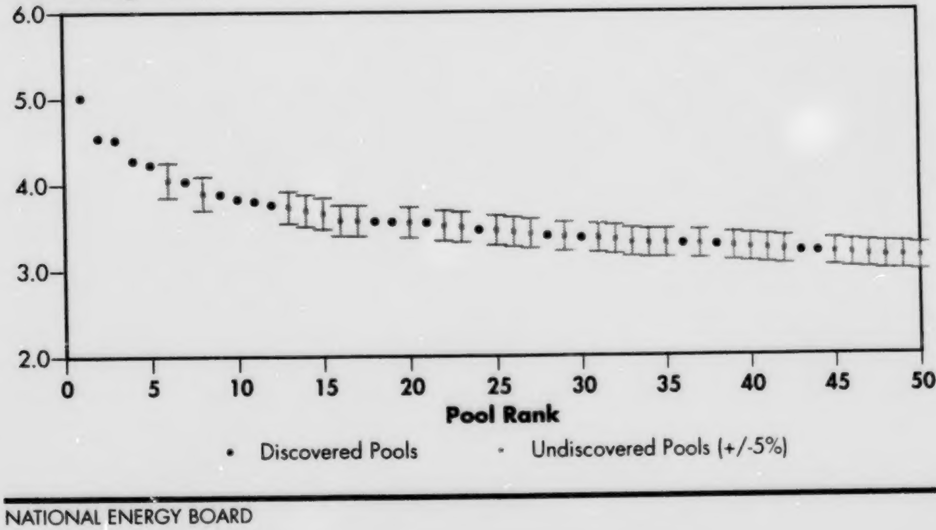


FIGURE 4.15

Cross Plot – Midale

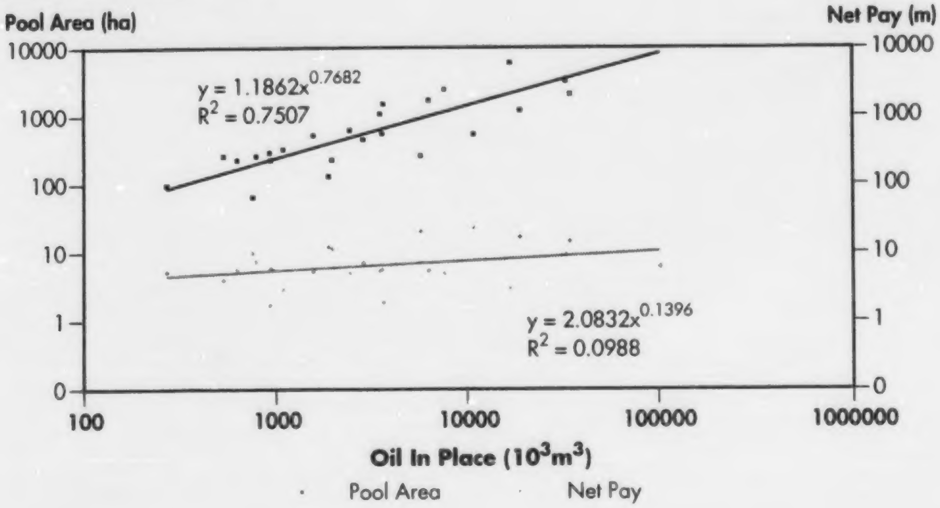
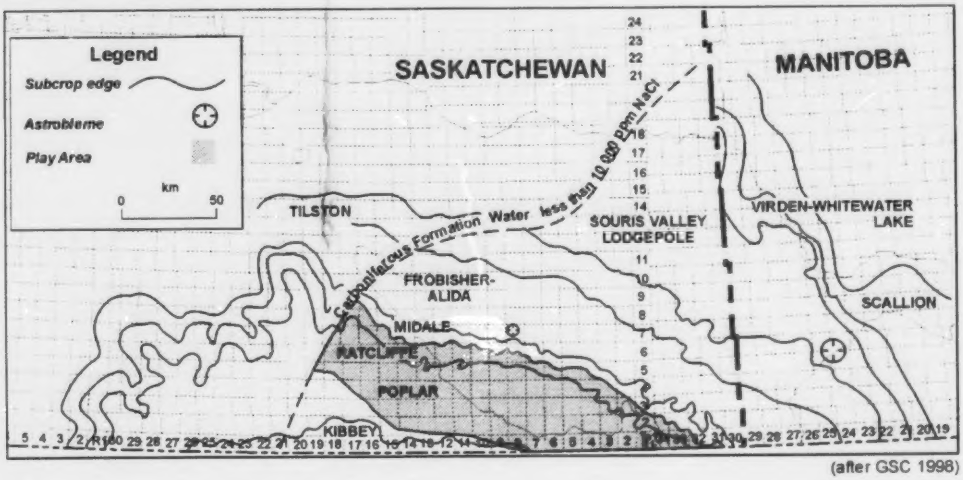


FIGURE 4.16

Ratcliffe Play Area


Legend
Subcrop edge
Astrobleme
Play Area
km
0
50
SASKATCHEWAN
MANITOBA
TILSTON
Carboniferous Formation Water less than 10 000 ppm NaCl
SOURIS VALLEY
LODGEPOLE
VIRDEN-WHITEWATER LAKE
FROBISHER-ALIDA
MIDALE
RATCLIFFE
POPLAR
SCALLION
KIBBEY

(after GSC 1998)

4.3.4 *Ratcliffe Play*

This play is defined to include oil pools in the Ratcliffe Beds of the Charles and Mission Canyon Formations. Pools formed by structural trapping are the most common in the central portion of the play area while stratigraphic traps resulting from porosity pinchout exist elsewhere. Similar to the Midale play boundaries, the Ratcliffe play edge has backstepped from the Midale subcrop edge (Figure 4.16). The Ratcliffe Beds are interbedded with three evaporite sequences which provide the vertical seal, and again, source rocks are believed to be the carbonates of the Madison Group and Bakken shales. Structural traps result from salt tectonics in the deeper Prairie Evaporite.

The Board's assessment is based on a discovered oil-in-place estimate of 12.5 million m^3 found in 20 discovered pools (Table 4.11). These discovered pools consist of five designated pools containing 9.7 million m^3 and 15 assigned miscellaneous pools containing 2.8 million m^3, about 30 percent of the designated pool volume. There are no potential pools for this play. The model projects an additional 566 undiscovered pools exist. They are expected to contain 57.2 million m^3 of oil in place (Table 4.12). The projected pools include 83 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture over 80 percent of the total undiscovered potential. The total resource estimate is 69.6 million m^3, of which 82 percent was undiscovered at year-end 1997.

TABLE 4.11

Ratcliffe – Heavy, Southern Saskatchewan

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
20	12,454	2,332	1,801	531	566	57,165	9,796	586	69,619	12,128	10,327

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Saskatchewan	2,332		Ave	Min	Max	Ave	Min	Max	1964
			1872	1723	1981	5.6	4.2	8.6	
Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	82
0.16	0.08	0.24	460	65	971	0.57	0.51	0.65	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
2	NEPTUNE	RATCLIFFE	19670709	3730.2	1	1	3968	3968	7
6	LAKE ALMA	RATCLIFFE	19650502	2379.4	2	3	3173	7141	12
9	SKINNER LAKE	RATCLIFFE	19681126	2090.8	3	4	2866	10007	18
14	Misc. # 1	RATCLIFFE		1533.9	4	5	2605	12612	22
18	HOFFER	RATCLIFFE	19640429	1267.8	5	7	2266	14878	26
30	Misc. # 2	RATCLIFFE		411.2	6	8	2146	17024	30
41	Misc. # 3	RATCLIFFE		242.8	7	10	1922	18946	33
52	FLAT LAKE	RATCLIFFE	19650611	191.8	8	11	1826	20772	36
					9	12	1728	22500	39
					10	13	1629	24129	42
					11	15	1453	25582	45
					12	16	1362	26944	47
					13	17	1278	28222	49
					14	19	1111	29333	51
					15	20	1028	30361	53
					16	21	942	31303	55
					17	22	864	32167	56
					18	23	782	32949	58
					19	24	712	33661	59
					20	25	647	34308	60
					21	26	590	34898	61
					22	27	489	35387	62
					23	28	451	35838	63
					24	29	417	36255	63
					25	31	387	36642	64
					26	32	361	37003	65
					27	33	340	37343	65
					28	34	320	37663	66
					29	35	305	37968	66
					30	36	293	38261	67
					31	37	280	38541	67
					32	38	269	38810	68
					33	39	251	39061	68
					34	40	244	39305	69
					35	42	237	39542	69
					36	43	232	39774	70
					37	44	226	40000	70
					38	45	221	40221	70
					39	46	216	40437	71
					40	47	212	40649	71

The largest undiscovered pool is expected to be the first ranked pool in this play at 4.0 million m^3, just slightly larger than the Neptune pool at 3.7 million m^3 (Figure 4.17). The cross plot information suggests that the largest undiscovered pool would occupy an area of 900 ha with an average net pay of about seven metres (Figure 4.18).

Approximately 65 percent of the wells in this play produced less than five thousand m^3 each and 80 percent of the wells produced less than 10 thousand m^3 each. These groups of wells accounted for five and 20 percent of the total production, respectively. Wells that produced between 10 and 30 thousand m^3 and wells that produced over 30 thousand m^3 accounted for about 40 percent of the total production each. The supply costs are estimated to be in the range of \$55-\$66 / m^3.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 54.3 to 58.4 million m^3 due to expansion of existing pools and inclusion of the miscellaneous volumes. There were no new pools found between year-end 1994 and year-end 1997.

TABLE 4.12

Ratcliffe Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^3m^3)	Number of Pools	OIP (10^3m^3)
10 - 100 million	0	0	0	0
1 - 10 million	5	11002	15	30360
100 - 1000 thousand	5	1127	68	16666
10 - 100 thousand	8	316	274	8997
<10 thousand	2	9	209	1142
Total	**20**	**12454**	**566**	**57164**

FIGURE 4.17

Pool Rank Plot – Ratcliffe

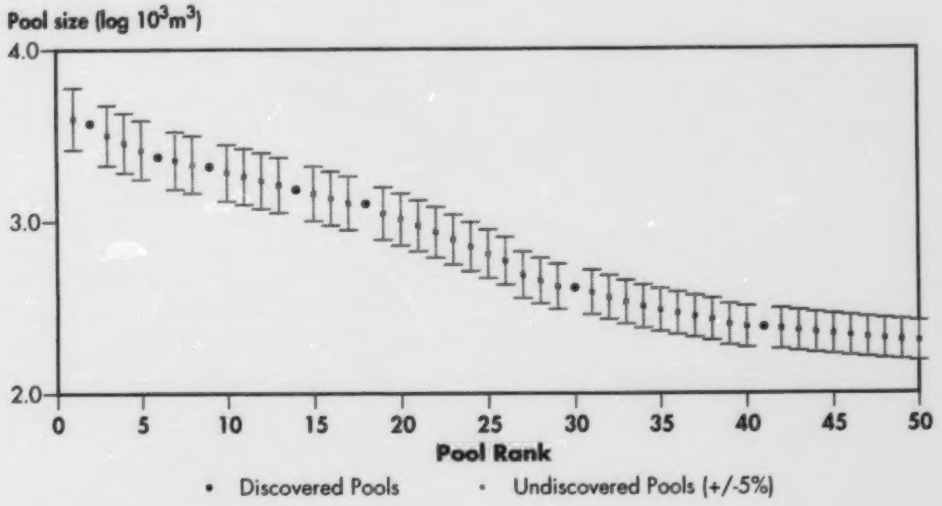
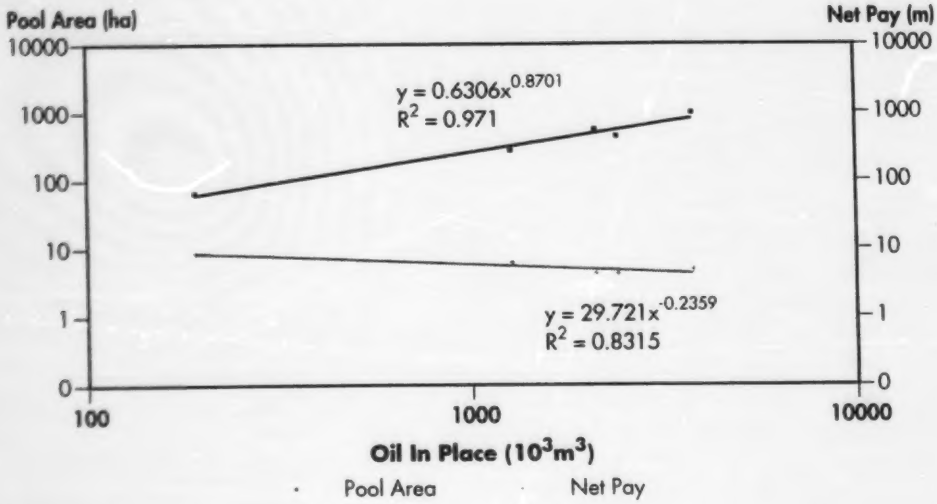


FIGURE 4.18

Cross Plot – Ratcliffe



4.3.5 *Bakken Play*

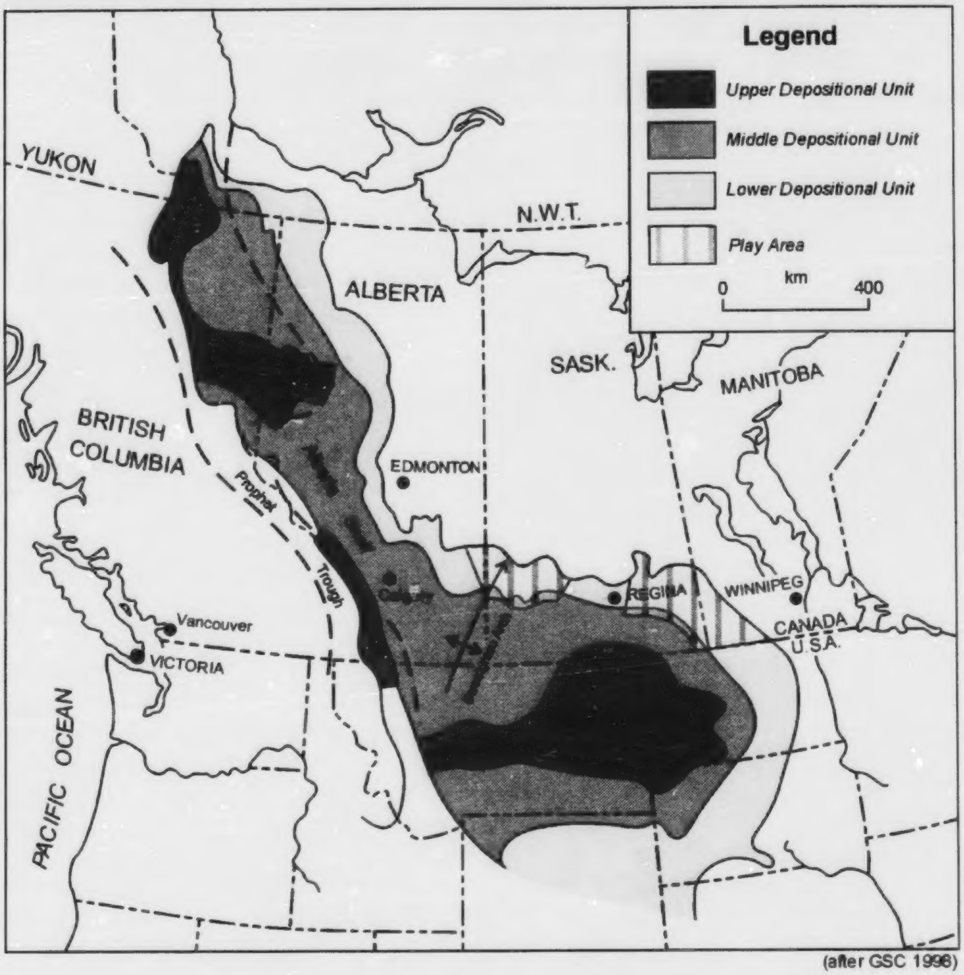
Depositionally, the Bakken Formation is located from northeastern British Columbia through to southwestern Manitoba (Figure 4.19). In B.C. and over most of Alberta, it consists of a black shale that is called the Exshaw Formation. However, in southeastern Alberta and east to Manitoba, the Bakken consists of two distinct units: a basal marine sandstone and a black organic-rich shale. The light and heavy crude oils found in the sandstone result from two separate source rocks. The light oil pools, found generally in southeastern Saskatchewan and southwestern Manitoba, were sourced from the shale unit and Lodgepole carbonates but were not subjected to any biodegradation. The heavy oil pools found in Alberta and western Saskatchewan were sourced from the shale unit and Lodgepole carbonates, which generated oil that migrated northwards and was subjected to a low to moderate amount of biodegradation. Most of the heavy oil pools are located in structural traps possibly related to the Sweetgrass Arch. Seals are provided by the overlying tight limestone units of the Upper Bakken or Pekisko Formation.

The Board's assessment is based on a discovered oil-in-place estimate of 277.6 million m^3, contained in 134 pools which consisted of 39 designated pools with an oil in place of 238.9 million m^3, and 95 assigned miscellaneous pools with an oil in place of 38.8 million m^3, about 16 percent of the volume in designated pools (Table 4.13). This was supplemented by the addition of 12 identified potential pools, containing 0.4 million m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model. The model projects an additional 2,092 undiscovered pools exist. They are expected to contain 69.5 million m^3 of oil in place (Table 4.14). The projected pools include 142 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture about half of the total undiscovered potential. The total resource estimate is 347.5 million m^3, of which 20 percent was undiscovered at year-end 1997/98.

The largest undiscovered pool should be the 23rd ranked pool in this fairly mature play and contain 1.5 million m^3 of oil in place. This is much smaller than the largest pool at Coleville, Saskatchewan, which contains 51.1 million m^3 (Figure 4.20). The cross plot information suggests that the largest undiscovered pool would occupy an area of about 150 ha with an average net pay of eight metres (Figure 4.21). Industry indicated that the undiscovered resource was too low given

FIGURE 4.19

Bakken Play Area


Legend
Upper Depositional Unit
Middle Depositional Unit
Lower Depositional Unit
Play Area
0 km 400
YUKON
N.W.T.
ALBERTA
SASK.
MANITOBA
BRITISH COLUMBIA
Prophet Trough
EDMONTON
Calgary
REGINA
WINNIPEG
CANADA
U.S.A.
Vancouver
VICTORIA
PACIFIC OCEAN

(after GSC 1998)

the number of recent discoveries. The Board supports the model's output but shares the industry's concern. Recent Bakken discoveries have been numerous (often more than one in a section), but of relatively small size. SEM has started assigning new discoveries to existing pools to ease the administrative burden. This could be a concern for future assessments if industry activity remains at current levels since the larger pools would be overstated, while the smaller pools would be understated both in number and volume.

Approximately 70 percent of the wells produced less than one thousand m^3 each and an additional 20 percent of the wells produced between one and five thousand m^3 each. These two groups captured approximately 12 percent of the total production. Approximately 20 percent of the production came from wells that produced from 10 and 30 thousand m^3 each and 60 percent came from the wells that produced over 30 thousand m^3. The average supply costs for the Bakken zone are estimated to be in the \$64- \$73/m^3 range.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 178.9 to 251.3 million m^3 due to new discoveries, expansion of existing pools, the

TABLE 4.13

Bakken – Heavy, Southeast Alberta and Southwest Saskatchewan

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
134	277,597	29,943	20,718	9,225	2104	69,911	6,127	2238	347,508	36,070	15,352

RESERVOIR PARAMETERS IN DISCOVERED POOLS									
Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Alberta	1,075		Ave	Min	Max	Ave	Min	Max	1951
Saskatchewan	28,868		827	739	964	5.6	1.1	11.5	
Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	20
0.27	0.07	0.33	390	16	2889	0.71	0.61	0.8	

Individual Pool Information									
Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	COLEVILLE (SK)	BAKKEN SAND	19510904	51071.6	1	23	1518	1518	2
2	PLOVER LAKE E (SK)	BAKKEN SAND	19801007	27092.1	2	26	1196	2714	4
3	LUSELAND (SK)	BAKKEN SAND	19790310	26823.1	3	31	876	3590	5
4	PLOVER LAKE (SK)	BAKKEN SAND	19740710	18520.1	4	33	801	4391	6
5	CACTUS LAKE (SK)	BAKKEN	19741129	17931.0	5	37	723	5114	7
6	COURT (SK)	BAKKEN SAND	19820315	16248.0	6	40	658	5772	8
7	NORTH HOOSIER (SK)	BAKKEN SAND	19650607	15319.0	7	43	604	6376	9
8	FUSILIER (SK)	BAKKEN SAND	19550000	10028.8	8	45	559	6935	10
9	HOOSIER (SK)	BAKKEN SAND	19730313	9853.0	9	47	527	7462	11
10	Misc. # 1	BAKKEN		9587	10	48	503	7965	11
11	COLEVILLE SOUTH (SK)	BAKKEN SAND	19830615	9167.0	11	50	480	8445	12
12	COURT SOUTH (SK)	BAKKEN SAND	19800328	5957.9	12	52	460	8905	13
13	BUFFALO COULEE (SK)	BAKKEN SAND	19520713	5081.9	13	53	450	9355	13
14	PLOVER LAKE W (SK)	BAKKEN SAND	19760917	4797.5	14	55	423	9778	14
15	BUFFALO COULEE N (SK)	BAKKEN SAND	19520930	4672.8	15	57	416	10194	15
16	Misc. # 2	BAKKEN		3650	16	60	395	10589	15
17	HEARTS HILL (SK)	BAKKEN SAND	19830305	3611.4	17	62	389	10978	16
18	NORTH SMILEY (SK)	BAKKEN SAND	19810619	2847.8	18	63	378	11356	16
19	MILTON (SK)	BAKKEN SAND	19941104	2760.7	19	64	373	11729	17
20	Misc. # 3	BAKKEN		2558	20	67	359	12088	17
21	Misc. # 4	BAKKEN		2001	21	68	354	12442	18
22	Misc. # 5	BAKKEN		1650	22	70	341	12783	18
24	Misc. # 6	BAKKEN		1406	23	71	337	13120	19
25	Misc. # 7	BAKKEN		1224	24	74	326	13446	19
27	Misc. # 8	BAKKEN		1082	25	75	322	13768	20
28	ALTARIO	BAKKEN A	19880126	980.0	26	76	318	14086	20
29	Misc. # 9	BAKKEN		969	27	78	310	14396	21
30	ESTHER	BAKKEN Q	19950821	893.0	28	79	307	14703	21
32	Misc. # 10	BAKKEN		875	29	80	300	15003	21
34	Misc. # 11	BAKKEN		797	30	82	292	15295	22
35	Misc. # 12	BAKKEN		730	31	84	285	15580	22
36	ESTHER	BAKKEN L	19850303	727.0	32	86	278	15858	23
38	ESTHER	BAKKEN E	19950814	681.0	33	87	275	16133	23
39	Misc. # 13	BAKKEN		672	34	89	267	16400	23
41	ESTHER	BAKKEN U	19960616	636.0	35	90	264	16664	24
42	Misc. # 14	BAKKEN		621	36	91	261	16925	24
44	Misc. # 15	BAKKEN		577	37	93	255	17180	25
46	Misc. # 16	BAKKEN		537	38	94	245	17425	25
49	Misc. # 17	BAKKEN		502	39	96	240	17665	25
51	Misc. # 18	BAKKEN		470	40	97	234	17899	26

inclusion of miscellaneous volumes and the Manitoba data. There were 25 new pools found between year-end 1994 and year-end 1998.

4.4 Resource Evaluation Overview

The major plays in this zone are Midale, Bakken, Mississippian Subcrop and Frobisher-Alida. Jointly, these four plays contain over 85 percent of the total oil in place for this zone. Almost 45 percent of that oil in place, mostly in Midale and Mississippian Subcrop plays, has not been discovered (Figure 4.22).

Seventy percent of the discovered reserves have already been produced. The Board estimates that two-thirds of future production will come from the undiscovered pools with the remainder coming from the discovered pools (Figure 4.23). An estimated 35 million m^3 of additional oil

TABLE 4.14

Bakken Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^{3}m^3)	Number of Pools	OIP (10^{3}m^3)
10 - 100 million	8	183034	0	0
1 - 10 million	17	71908	2	2714
100 - 1000 thousand	60	20718	140	29856
10 - 100 thousand	55	2326	1132	32709
<10 thousand	6	31	818	4213
Total	**146**	**278013**	**2092**	**69492**

FIGURE 4.20

Pool Rank Plot – Bakken

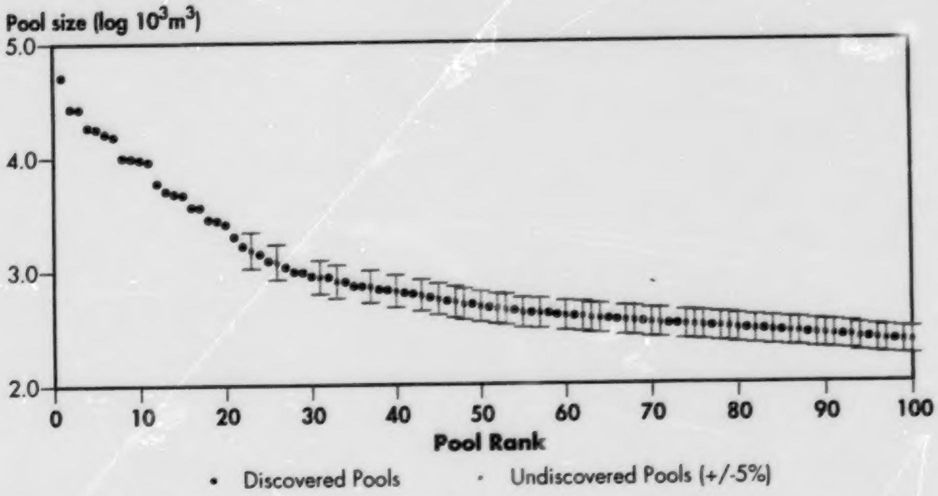
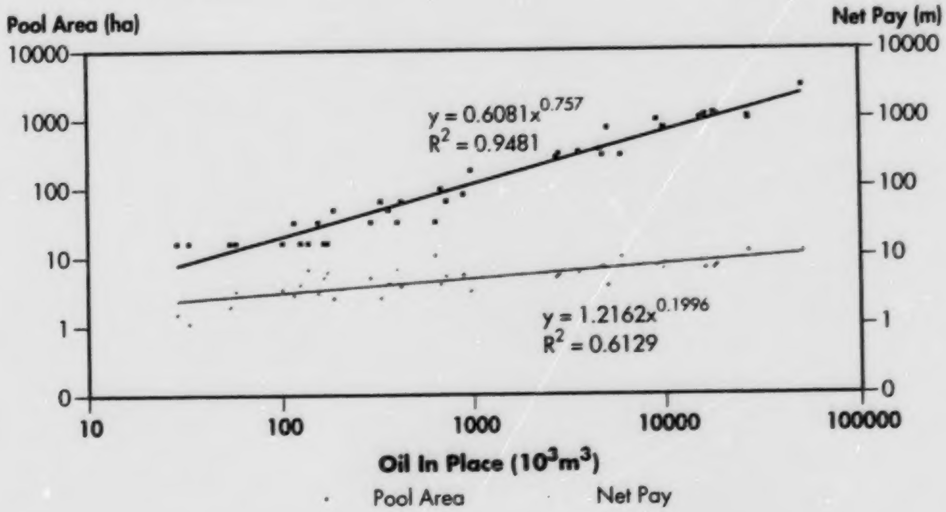


FIGURE 4.21

Cross Plot – Bakken



could be recovered through the application of new technology or through improvements to current production practices. An additional 18 million m^3 could be recovered from the Midale pools alone due to their reservoir properties, such as good porosity and higher quality crude oil.

The average recovery factors for the Carboniferous plays are estimated to be in the 10 to 20 percent range for discovered pools and six to 17 percent for the undiscovered pools; the lower recovery factors for undiscovered pools can be attributed to the smaller pool sizes.

FIGURE 4.22

Initial Volume In Place – Carboniferous

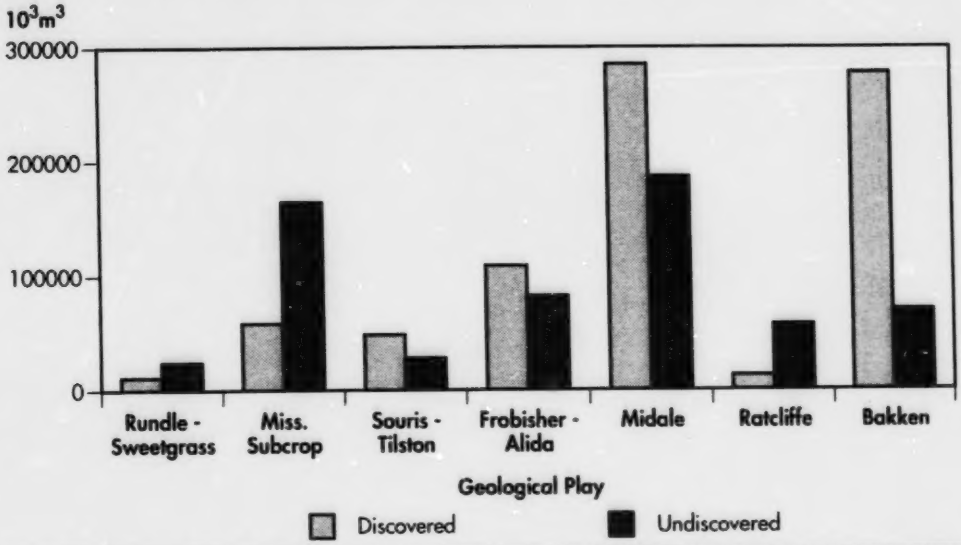
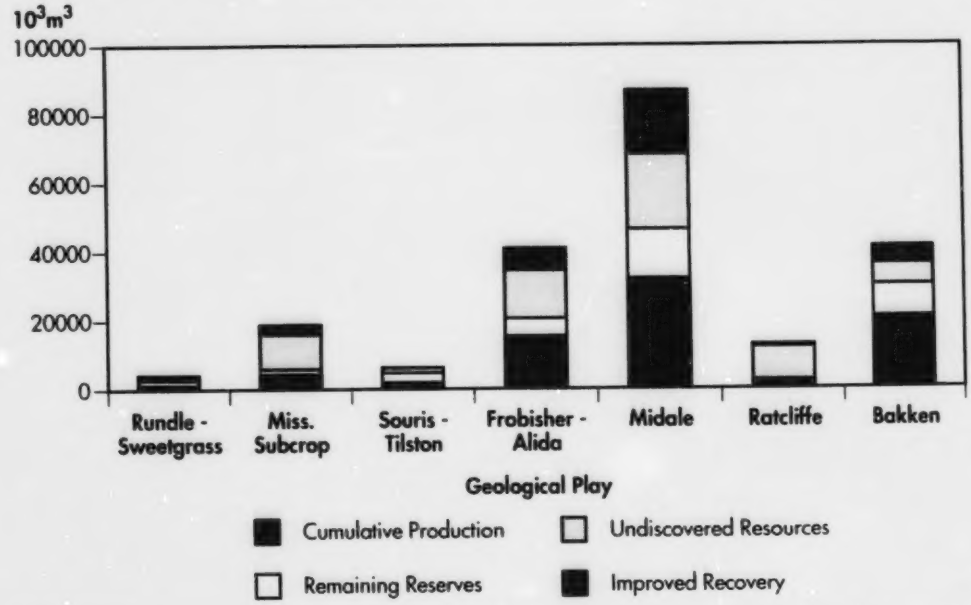


FIGURE 4.23

Recoverable Volumes – Carboniferous



4.4.1 *Bakken Play*

The Board projects the total number of pools in this play to be 2,238. Only seven percent of those pools, or 146 pools, have been discovered to date. Almost 90 percent of the pools have an oil-in-place volume of less than 100 thousand m^3 (Figure 4.24).

About 80 percent of the play's total oil-in-place volume is contained in the discovered pools, with two-thirds of that volume captured by a group of only eight pools that each have an oil-in-place volume of more than 10 million m^3. The remaining 20 percent is found in the undiscovered pools and is essentially distributed among the many pools with less than one million m^3 (Figure 4.25). As expected, over one-half of the play's recoverable volumes are captured in the eight large discovered pools. Only 17 percent of the play's recoverable volumes are found in the undiscovered pools.

The range of recovery factors for this group of pools is shown in Figure 4.24. It is interesting to note that although pools with oil-in-place volumes of between 10 and 100 million m^3 provided the largest recoverable volumes, they did not have the highest recovery factors (Figure 4.26). The highest recovery factors are found in pools containing between one and 10 million m^3. Net pays in these pools tend to be thicker and the concentration of oil in a smaller area may contribute to more efficient recovery.

The Board estimates that 60 percent of future production will come from the remaining reserves in the discovered pools and 40 percent from the undiscovered pools. It is estimated that an additional five million m3 of oil could be recovered from existing Bakken pools through optimized production practices and initiation of additional enhanced recovery schemes.

FIGURE 4.24

Pool Size Distribution – Bakken

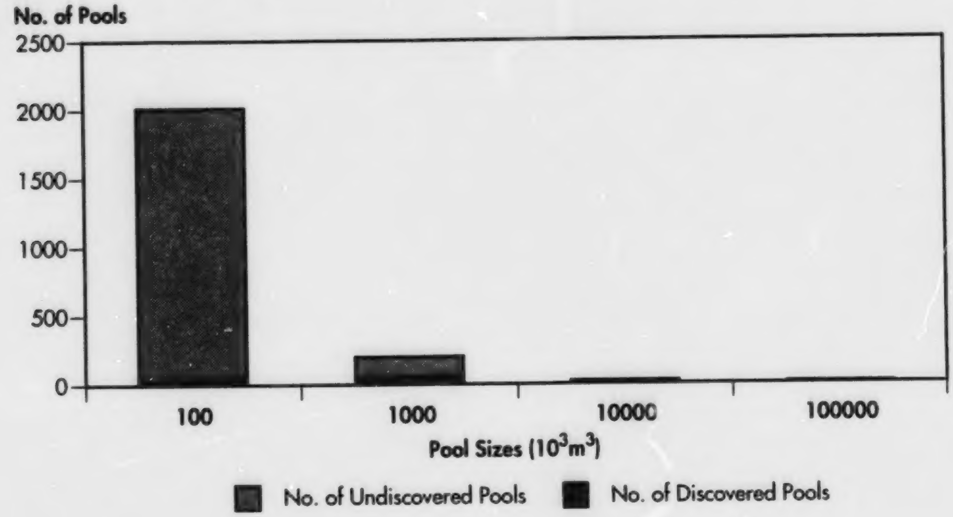


FIGURE 4.25

Recoverable Volumes by Source and Pool Size - Bakken

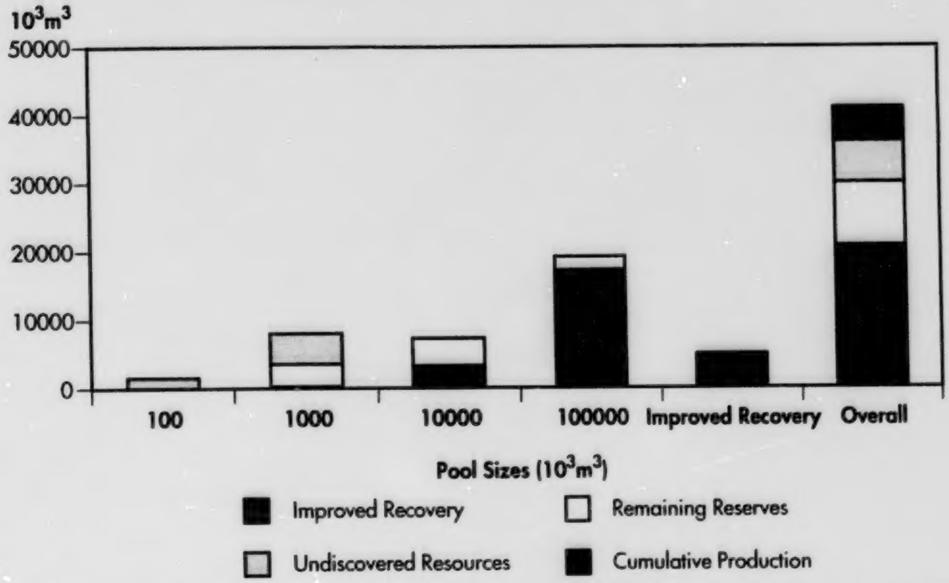
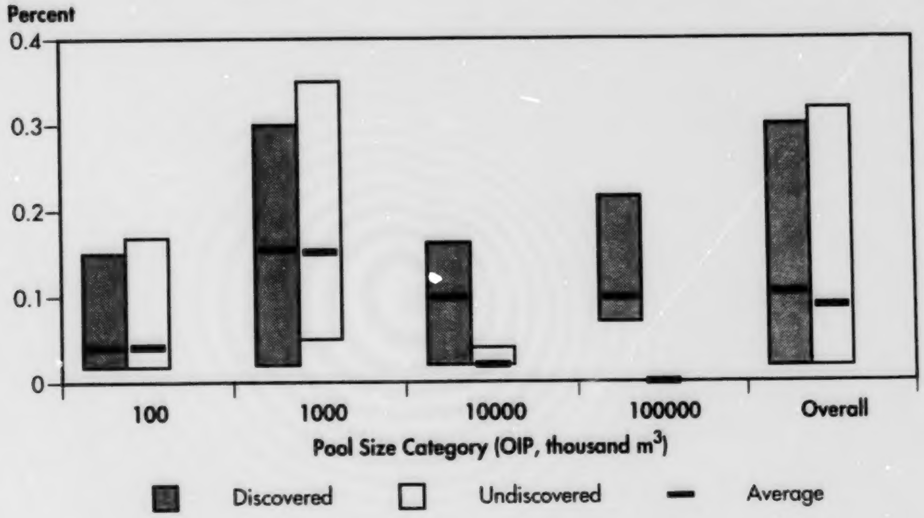


FIGURE 4.26

Recovery Factors - Bakken



4.5 Summary

The oil-in-place volumes of light and heavy oils for all plays in the Carboniferous zones has increased since the last review by the GSC, from 2 857.6 to 4 210.9 million m^3, a growth of 47 percent. Heavy oil represents about one-third of the NEB's total oil-in-place volume. While a significant portion of the growth is due to the inclusion of the miscellaneous volumes, there has also been growth in the existing pools and some new discoveries made. There were a total of 97 new pools discovered between year-end 1994 and year-end 1997/98.

There are seven plays in the Carboniferous zone. The two largest plays, Midale and Bakken, account for about 60 percent of the total oil-in-place volume (Table 4.15). Approximately 43 percent of the estimated volume remains to be discovered. The estimated recovery factors for the discovered and undiscovered pools are approximately 14 and 11 percent, respectively. It is estimated that the production from improved recovery schemes will account for an additional recovery of 2.5 percent of the total oil-in-place volume.

The Board's analysis of the heavy oil pools indicates that there is a significant amount of heavy oil left to be found in these Carboniferous plays in the provinces of British Columbia, Alberta and Saskatchewan. For the most part, the undiscovered pools will be smaller than the discovered pools; however, there are still a few large pools projected to be found. The discovery of these large pools may require development of a new exploration strategy. Some may already be found but not yet recognized and some of these pools may result from the future amalgamation of a number of smaller recognized or miscellaneous pools, after aggressive pool extension drilling.

TABLE 4.15

Resources of Carboniferous Plays (10^6m^3)

Play	Discovered		Undiscovered	
	Oil in Place	Recoverable	Oil In Place	Recoverable
Rundle Sweetgrass	11.2	1.2	24.1	1.7
Mississippian Subcrop	58.4	5.9	164.4	10.1
Souris-Tilston	48.5	2.0	28.1	1.4
Frobisher-Alida	108.6	20.5	82.1	14.0
Midale	284.9	46.3	186.4	21.9
Ratcliffe	12.5	2.3	57.2	9.8
Bakken	277.6	29.9	69.9	6.1
Total	**801.7**	**108.1**	**612.2**	**65.0**

CHAPTER FIVE

5. Jurassic Zone Play Results

5.1 Geological Overview

Jurassic deposition in the WCSB occurred in shelf conditions over much of the basin and in deeper water conditions in the western portions of the basin. It is believed that there was extensive deposition of Jurassic aged sediments, but those deposits were subjected to intense erosional conditions leaving only remnants. Three major depositional cycles occurred with each cycle characterized by coarsening-upwards or shallowing-upwards conditions. The first cycle had two basin fill events, one represented by shale and siltstone deposits of the Nordegg Formation in the west and carbonates and quartz-chert sandstones further east. The second event is represented by deposits of siltstone, limestone and shale, and may include the prolific channel sandstone pools in western Alberta. The second cycle of basin fill is comprised of the Poker Chip shale unit and the Rock Creek sandstone deposits. These first two cycles were primarily filled by sediments coming from the northeast to the southwest. Following the Columbian orogeny, the third cycle of basin fill was dominated by sediments derived from the west and filling to the east. The third cycle deposits are represented by the Kootenay-Nikanassin Formations.

Light and heavy oils in these plays are found in sandstone deposits in either stratigraphic traps or in structural traps resulting from drape over older topographic highs. Stratigraphic traps result from deposition on uneven erosional surfaces, isolation by erosion or by updip porosity pinchouts. Seals are provided by Jurassic aged or younger shales, siltstones and tight sandstones. Source rocks are believed to be Carboniferous or younger aged shales.

5.2 Williston Basin Region

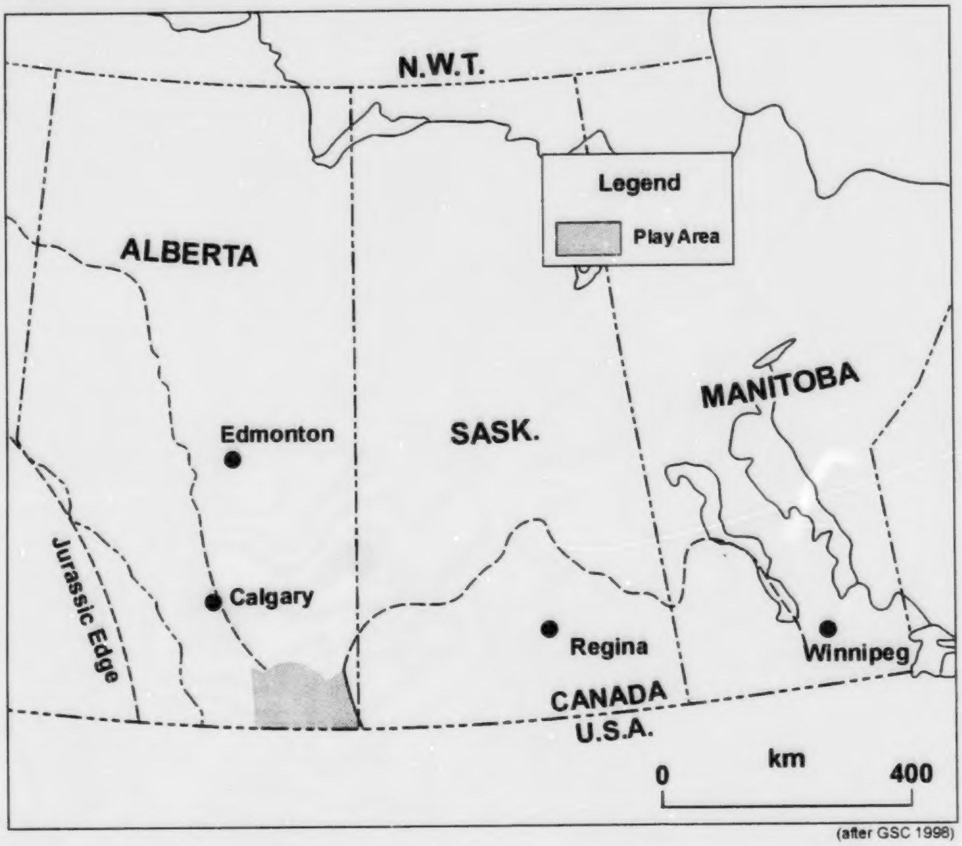
5.2.1 Sawtooth Play

This play includes the heavy oil pools in the Sawtooth Formation sandstone on the Sweetgrass Arch. It is limited by deposition to the east and west, erosion to the north and by the international border to the south (Figure 5.1). Both stratigraphic and structural traps are present in this mature play, and the majority of the pools contain heavy oil.

The Board's assessment is based on a discovered oil-in-place estimate of 90.2 million m^3, contained in 188 designated pools (Table 5.1). This was supplemented by the addition of 102 identified potential pools, containing 3.5 million m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model (Table 5.2). There were no identified miscellaneous pools for this play. The model projects an additional 1,422 undiscovered pools exist. They are expected to contain 30.1 million m^3 of oil in place. The projected pools include 46 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture 23 percent of the total undiscovered potential. The total resource estimate is 123.8 million m^3, of which 27 percent was undiscovered at year-end 1998.

FIGURE 5.1

Sawtooth Play Area



(after GSC 1998)

The largest undiscovered pool in this mature play is expected to be only the 50th ranked pool with 0.5 million m^3 of oil in place. This is dwarfed by the Ronalane Sawtooth B pool containing five million m^3 (Figure 5.2). The cross plot information suggests that the largest undiscovered pool would occupy an area of only 90 ha with an average net pay of six metres (Figure 5.3). Industry comments varied on this play, with some indicating that the undiscovered resource and the largest undiscovered pool were too small and others indicating that the largest pool size was reasonable, but that the resource was overstated. One reply indicated that the minimum pool size should be increased to 160 thousand m^3. The Board considered the effect of revising the minimum pool size and found that it would reduce the number of developable undiscovered pools to just 17, with an undiscovered resource of 4.0 million m^3, one percent of the apparent play potential. The Board's supply cost analysis indicated that pools smaller than the proposed cut-off size were still viable. The Board decided to proceed with the results as provided by the geological model.

Approximately 35 percent of the wells produced less than five thousand m^3 each, accounting for less than two percent of the total production. However, approximately 40 percent of the wells produced more than 10 thousand m^3 each, while 25 percent of the wells produced over 20 thousand m^3. Approximately 95 percent of the total production was captured by wells producing more than 20 thousand m^3. The average supply costs for the Sawtooth play are estimated to be in the economic range of \$42-\$46/ m^3 (Supply costs are discussed in Chapter 7).

In comparison with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 81.8 to 92.6 million m^3 due to new discoveries and growth in existing pools. There were 31 new pools found between year-end 1994 and year-end 1998.

TABLE 5.1

Sawtooth – Heavy, Southern Alberta

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
188	90,245	28,300	24,376	3,924	1524	33,544	2,714	1,712	123,789	31,014	6,638

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^{3}m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Alberta	28,300		Ave	Min	Max	Ave	Min	Max	1944
			936	846	1032	3.7	0.5	14.7	
Porosity			**Area**			**Oil Saturation**			**% Undiscovered**
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	27
0.22	0.12	0.29	105	8	1475	0.62	0.27	0.83	

Individual Pool Information

Discovered Pools (10^{3}m^3)					Undiscovered Pools (10^{3}m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	RONALANE	SAWTOOTH B	19901204	5083	1	50	456	456	1
2	GRAND FORKS	SAWTOOTH O	19660215	4429	2	61	366	822	2
3	GRAND FORKS	SAWTOOTH MM	19800823	4351	3	66	320	1142	3
4	GRAND FORKS	SAWTOOTH WW	19870722	3812	4	72	277	1419	4
5	GRAND FORKS	SAWTOOTH OO	19710000	2687	5	77	250	1669	5
6	CONRAD	ELLIS	19911009	2540	6	83	233	1902	6
7	GRAND FORKS	SAWTOOTH T	19851031	2500	7	85	224	2126	6
8	ENCHANT	ELLIS L	19651017	2337	8	92	211	2337	7
9	RONALANE	SAWTOOTH V	19910411	2167	9	95	204	2541	8
10	GRAND FORKS	SAWTOOTH SS	19800818	2048	10	97	197	2738	8
11	HAYS	SAWTOOTH B	19850226	1981	11	99	189	2927	9
12	GRAND FORKS	SAWTOOTH L	19850503	1940	12	102	185	3112	9
13	GRAND FORKS	SAWTOOTH Q	19750226	1839	13	109	180	3292	10
14	GRAND FORKS	SAWTOOTH PPP	19911218	1777	14	112	173	3465	10
15	GRAND FORKS	SAWTOOTH D	19861029	1727	15	113	170	3635	11
16	ENCHANT	ELLIS D	19921112	1690	16	117	165	3800	11
17	GRAND FORKS	SAWTOOTH N	19870916	1670	17	118	162	3962	12
18	HAYS	SAWTOOTH C	19850415	1524	18	120	158	4120	12
19	SKIFF	SAWTOOTH A	16941018	1431	19	124	155	4275	13
20	RONALANE	SAWTOOTH K	19900626	1231	20	126	151	4426	13
21	GRAND FORKS	SAWTOOTH II	19891215	1173	21	129	148	4574	14
22	GRAND FORKS	SAWTOOTH U	19730206	1072	22	132	143	4717	14
23	RONALANE	SAWTOOTH C	19751105	1050	23	134	141	4858	14
24	RONALANE	SAWTOOTH J	19920406	1022	24	136	137	4995	15
25	GRAND FORKS	SAWTOOTH A	19841013	1013	25	139	135	5130	15
26	RED COULEE	CUTBANK B	19600606	1010	26	141	134	5264	16
27	GRAND FORKS	SAWTOOTH W	19790225	924	27	144	130	5394	16
28	GRAND FORKS	SAWTOOTH NN	19711026	917	28	146	128	5522	16
29	ENCHANT	ELLIS C	19921109	908	29	148	126	5648	17
30	HAYS	SAWTOOTH D	19850524	876	30	150	124	5772	17
31	BOW ISLAND	SAWTOOTH D	19821227	807	31	153	121	5893	18
32	GRAND FORKS	SAWTOOTH VV	19850905	761	32	155	119	6012	18
33	RONALANE	SAWTOOTH L	19930530	750	33	157	117	6129	18
34	GRAND FORKS	SAWTOOTH CCC	19900821	688	34	158	116	6245	19
35	GRAND FORKS	SAWTOOTH LL	19791101	676	35	160	114	6359	19
36	RONALANE	SAWTOOTH O	19930619	585	36	161	112	6471	19
37	GRAND FORKS	SAWTOOTH B2B	19921023	575	37	163	112	6583	20
38	ENCHANT	ELLIS I	19531102	571	38	165	110	6693	20
39	CHIN COULEE	SAWTOOTH B	19940000	559	39	167	109	6802	20
40	GRAND FORKS	SAWTOOTH ZZ	19871015	534	40	172	107	6909	21

TABLE 5.2

Sawtooth Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m³)	Number of Pools	OIP (10³m³)	Number of Pools	OIP (10³m³)
10 - 100 million	0	0	0	0
1 - 10 million	26	55104	0	0
100 - 1000 thousand	112	33220	46	7532
10 - 100 thousand	128	5222	724	18834
<10 thousand	25	163	652	3713
Total	**290**	**93707**	**1422**	**30079**

FIGURE 5.2

Pool Rank Plot – Sawtooth

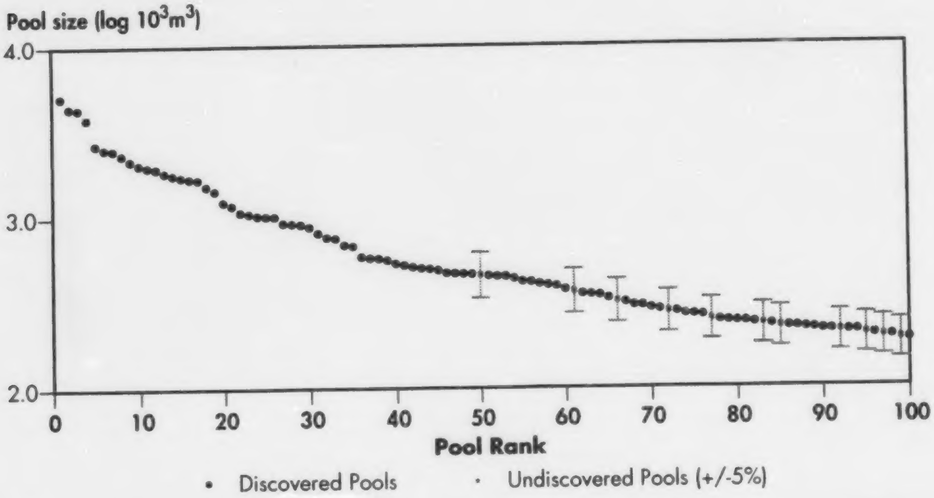
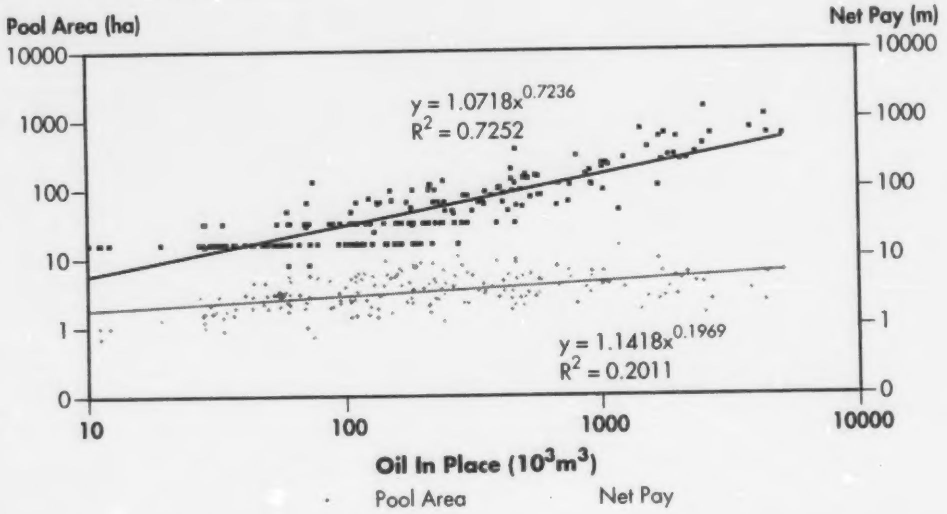


FIGURE 5.3

Cross Plot – Sawtooth



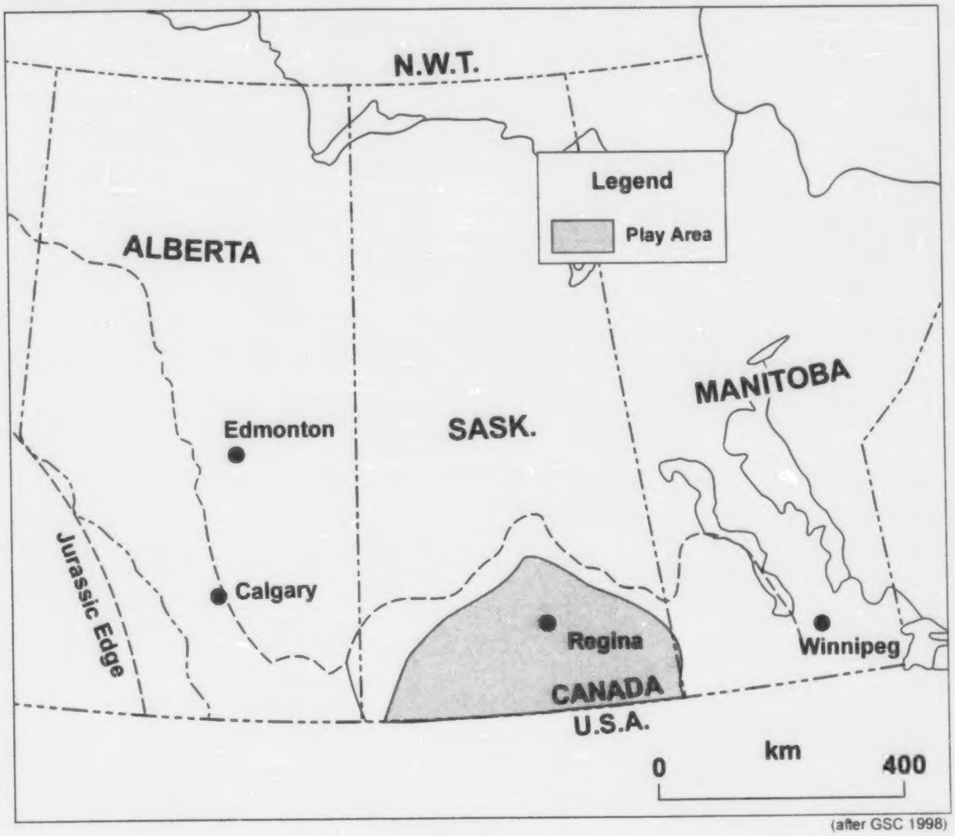
5.2.2 *Shaunavon Play*[1,2]

This play was originally defined to include only the oil pools in the Upper and Lower Shaunavon shallow marine and shoreline sandstones along the east flank of the Sweetgrass Arch in southwestern Saskatchewan. It has since been expanded to include the Jurassic Red Jacket sandstone pools in southeastern Saskatchewan. This is because the Red Jacket sands are directly equivalent to the Upper Gravelbourg and Shaunavon sections (Figure 5.4). They have a similar style of trapping and are also sourced by Lodgepole carbonates. Lateral sealing is provided by the tight sediments of the same formations and all pools contain heavy oil.

The Board's assessment is based on a discovered oil-in-place estimate of 267.7 million m^3 found in 131 discovered pools (Table 5.3). These discovered pools consist of 47 designated pools containing 253.9 million m^3 and 84 assigned miscellaneous pools containing 13.8 million m^3, about five `percent of the volume found in the designated pools. There are no potential pools for this play.

FIGURE 5.4

Shaunavon Play Area



(after GSC 1998)

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[1] Canadian Society of Petroleum Geologists, *Lexicon of Canadian Stratigraphy, Volume 4, Western Canada Including Eastern British Columbia, Alberta, Saskatchewan and Southern Manitoba*, Editor: D.J. Glass, 1990

[2] Canadian Society of Petroleum Geologists and Alberta Research Council, *Geological Atlas of the Western Canada Sedimentary Basin*, Compiled by G. Mossup and I.. Shetsen, 1994

TABLE 5.3

Shaunavon – Heavy, Southwest Saskatchewan

Discovered Pools					**Undiscovered Pools**			**Total Resources**			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
131	267,663	57,764	47,782	9,982	895	203,367	27,485	1026	471,030	85,249	37,467

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Saskatchewan	57,764		Ave	Min	Max	Ave	Min	Max	1952
			1187	596	1505	5.3	1.7	13.1	
Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	43
0.18	0.12	0.31	1035	32	4782	0.73	0.45	0.95	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	DOLLARD	UPPER SHAUNAVON	19870919	28486	1	2	25171	25171	12
3	INSTOW	UPPER SHAUNAVON	19540620	24231	2	6	16169	41340	20
4	RAPDAN	UPPER SHAUNAVON	19530131	23859	3	10	10871	52211	26
5	BUTTE	UPPER SHAUNAVON	19670303	19214	4	12	8878	61089	30
7	DELTA	UPPER SHAUNAVON	19560527	13544	5	15	8135	69224	34
8	BUTTE WEST	UPPER SHAUNAVON	19670000	12869	6	17	7484	76708	38
9	BONE CREEK	UPPER SHAUNAVON	19541009	12207	7	21	6463	83171	41
11	LEITCHVILLE	SHAUNAVON	19600428	8943	8	23	5958	89129	44
13	WHITEMUD	SHAUNAVON	19630116	8650	9	25	5452	94581	47
14	NORTH PREMIER	UPPER SHAUNAVON	19530315	8302	10	28	4805	99386	49
16	SUFFIELD	UPPER SHAUNAVON	19541120	7543	11	29	4591	103977	51
18	BENCH	UPPER SHAUNAVON	19690204	7257	12	32	3980	107957	53
19	GULL LAKE NORTH	UPPER SHAUNAVON	19530803	7219	13	33	3803	111760	55
20	LEON LAKE	SHAUNAVON	19531203	6911	14	37	3207	114967	57
22	RAPDAN WEST	SHAUNAVON	19550719	6367	15	38	3024	117991	58
26	CLINTONVILLE	SHAUNAVON	19850908	4921	16	40	2650	120641	59
27	GARDENHEAD	UPPER SHAUNAVON	19930000	4850	17	42	2529	123170	61
30	EASTBROOK	SHAUNAVON	19660523	4470	18	43	2393	125563	62
31	RED JACKET	RED JACKET SAND	19840224	4425	19	44	2169	127732	63
34	Misc. # 1	SHAUNAVON		3705	20	45	1994	129726	64
35	ILLERBRUN	UPPER SHAUNAVON	19650523	3620	21	46	1993	131719	65
36	GULL LAKE CENTRAL	UPPER SHAUNAVON	19530130	3467	22	48	1870	133589	66
39	EASTEND	SHAUNAVON	19520901	2776	23	51	1819	135408	67
41	NOTUKEU	UPPER SHAUNAVON	19690309	2541	24	53	1724	137132	67
47	COOTHILL	RED JACKET SAND	19660306	1872	25	54	1684	138816	68
49	GULL LAKE SOUTH	UPPER SHAUNAVON	19520000	1856	26	57	1602	140418	69
50	BATTLE CREEK S.	UPPER SHAUNAVON	19880107	1822	27	59	1516	141934	70
52	ANTELOPE LAKE	UPPER SHAUNAVON	19640000	1755	28	60	1415	143349	70
55	COVINGTON WEST	UPPER SHAUNAVON	19690000	1643	29	62	1364	144713	71
56	RAPDAN NORTH	LOWER SHAUNAVON	19690000	1634	30	63	1305	146018	72
58	MOOSOMIN	RED JACKET SAND	19840303	1593	31	65	1254	147272	72
61	Misc. # 2	SHAUNAVON		1377	32	67	1143	148415	73
64	COVINGTON	UPPER SHAUNAVON	19690725	1287	33	68	1114	149529	74
66	RED JACKET SOUTH	RED JACKET SAND	19891228	1218	34	69	1090	150619	74
71	Misc. # 3	SHAUNAVON		955	35	70	1037	151656	75
75	RAPDAN SOUTH	UPPER SHAUNAVON	19840000	882	36	72	946	152602	75
78	CHAMBERY	UPPER SHAUNAVON	19530330	799	37	73	908	153510	75
80	DELTA WEST	UPPER SHAUNAVON	19530607	781	38	74	895	154405	76
81	Misc. # 4	SHAUNAVON		741	39	76	845	155250	76
					40	77	821	156071	77

The model projects an additional 896 undiscovered pools exist. They are expected to contain 203.4 million m^3 of oil in place (Table 5.4). The projected pools include 156 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture over 90 percent of the total undiscovered potential. The total resource estimate is 471.0 million m^3, of which 43 percent was undiscovered at year-end 1997.

The largest undiscovered pool is expected to be the second ranked pool at 25.2 million m^3, behind only the Dollard pool which contains 28.5 million m^3 (Figure 5.5). The cross plot information suggests that the largest undiscovered pool would occupy 5,000 ha with about seven metres of average net pay (Figure 5.6). The only industry response noted the inclusion of pools outside the original play area. The Board expanded the play definition. The expanded play area should also

TABLE 5.4

Shaunavon Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m³)	Number of Pools	OIP (10³m³)	Number of Pools	OIP (10³m³)
10 - 100 million	7	134410	3	52211
1 - 10 million	28	117687	32	99446
100 - 1000 thousand	36	13751	121	37239
10 - 100 thousand	42	1734	378	13014
<10 thousand	18	82	362	1457
Total	131	267664	896	203366

FIGURE 5.5

Pool Rank Plot – Shaunavon

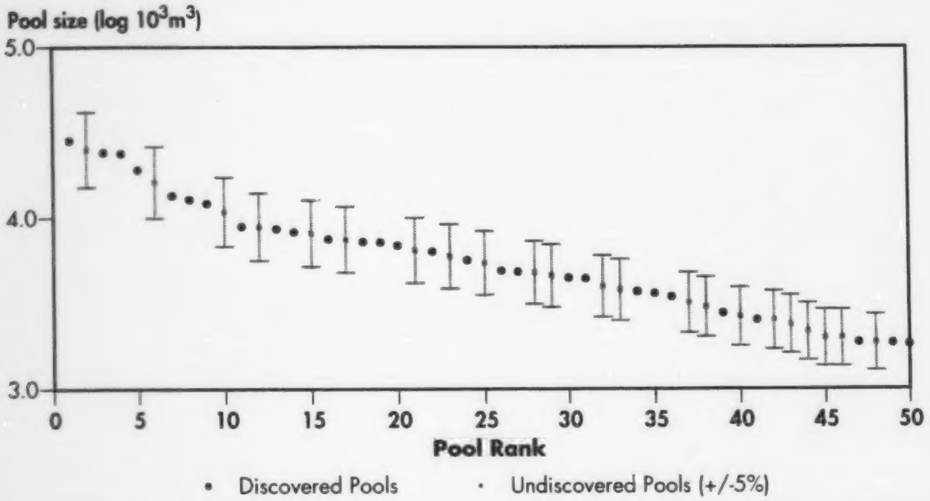
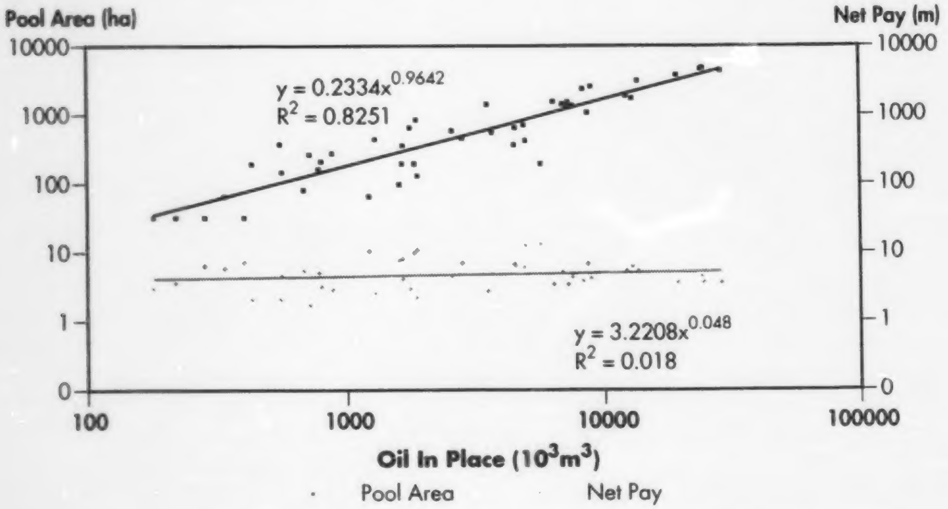


FIGURE 5.6

Cross Plot – Shaunavon



provide additional lands for new exploration efforts, especially in the sparsely drilled area between Regina and Swift Current, Saskatchewan.

One-half of the wells have produced less than five thousand m^3, capturing less than three percent of the total production. Conversely, 15 percent of the wells produced over 50 thousand m^3 each, accounting for about 80 percent of the total production. The play's average supply cost is \$36-\$38/m^3, the lowest of all the conventional heavy oil plays studied, making the Shaunavon play an attractive target economically.

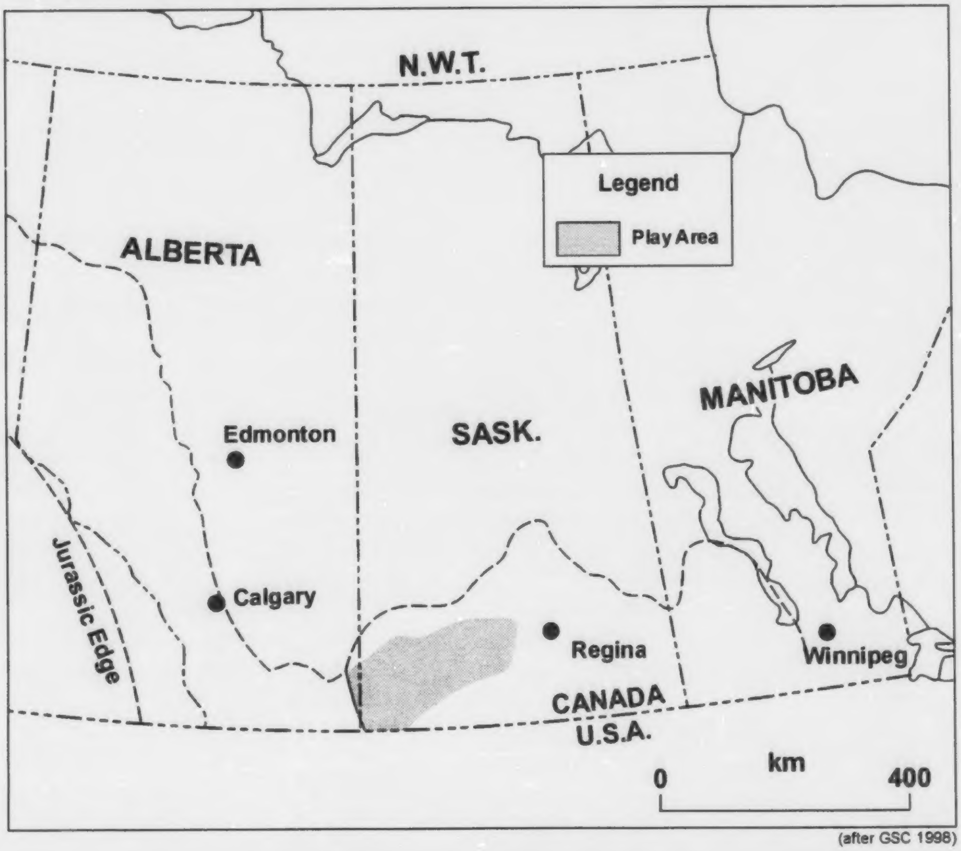
Compared with the GSC's 1998 report, the discovered oil in place for heavy oil has increased from 228.7 to 251.9 million m^3 due to growth in existing pools and the inclusion of miscellaneous volumes. There were no new pools found between year-end 1994 and year-end 1997.

5.2.3 Roseray-Success Play

This play is defined to include the oil pools in the sandstones of the Roseray and Success Formations of southern Saskatchewan. The trapping mechanism for these pools is a result of stratigraphic facies changes and unconformity traps. Seals are provided by equivalent-aged shales or by tight sandstones of the same age or younger. Source rocks are believed to be from those same shales or from deeper Carboniferous carbonates. The play is found in southwestern Saskatchewan, north and northeast of the original Shaunavon play (Figure 5.7).

FIGURE 5.7

Roseray-Success Play Area



(after GSC 1998)

The Board's assessment is based on a discovered oil-in-place estimate of 187.2 million m^3 found in 96 discovered pools (Table 5.5). These discovered pools consist of 25 designated pools containing 171.9 million m^3 and 71 assigned miscellaneous pools containing 15.3 million m^3, about nine percent of the volume found in the designated pools. There are no potential pools for this play. The model projects an additional 1,470 undiscovered pools exist. They are expected to contain 99.3 million m^3 of oil in place (Table 5.6). The projected pools include 172 pools that are expected to contain more than 100 thousand m^3 of oil in place each; these capture about 75 percent of the total undiscovered potential. The total resource estimate is 286.5 million m^3, of which 35 percent was undiscovered at year-end 1997.

TABLE 5.5

Roseray-Success – Heavy, Southwest Saskatchewan

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
96	187,176	63,998	49,145	14,853	1470	99,334	10,802	1,566	286,510	74,800	25,655

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)		Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
		Ave	Min	Max	Ave	Min	Max	
Saskatchewan	63,998	958	788	1075	5.7	2.4	13.1	1952

Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	
0.26	0.22	0.31	657	49	3672	0.69	0.58	0.8	35

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	BATTRUM	ROSERAY SAND	19550129	51273.0	1	10	5839	5839	6
2	FOSTERTON	ROSERAY SAND	19520113	25193.0	2	15	3325	9164	9
3	CANTUAR	ROSERAY SAND	19520910	14939.0	3	16	2966	12130	12
4	SUFFIELD	ROSERAY SAND	19540000	11554.0	4	17	2595	14725	15
5	SOUTH SUCCESS	ROSERAY SAND	19530000	11059.0	5	19	2216	16941	17
6	VERLO	ROSERAY SAND	19560501	9786.6	6	20	2057	18998	19
7	NORTH PREMIER	ROSERAY SAND	19530121	9383.0	7	22	1705	20703	21
8	MAIN SUCCESS	ROSERAY SAND	19521029	6858.1	8	25	1463	22166	22
9	BEVERLEY	ROSERAY SAND	19521025	6033.0	9	27	1418	23584	24
11	CANTUAR EAST	ROSERAY SAND	19520000	4980.0	10	28	1362	24946	25
12	Misc. # 1	R-S		4334.9	11	29	1195	26141	26
13	COLEVILLE SOUTH	SUCCESS	19850000	3794.1	12	31	1128	27269	27
14	MILTON	SUCCESS	19800000	3479.0	13	33	1085	28354	29
18	LOVERNA	SUCCESS	19521029	2492.7	14	35	1003	29357	30
21	HAZLET	ROSERAY SAND	19630907	1984.0	15	37	991	30348	31
23	BATTRUM NORTH	ROSERAY SAND	19790725	1678.0	16	38	913	31261	31
24	Misc. # 2	R-S		1587.4	17	39	885	32146	32
26	SUCCESS ALPHA	ROSERAY SAND	19530520	1440.0	18	41	828	32974	33
30	FOSTERTON SOUTH	ROSERAY SAND	19650000	1173.8	19	42	800	33774	34
32	Misc. # 3	R-S		1093.9	20	43	769	34543	35
34	SUCCESS NORTH	ROSERAY SAND	19660817	1038.1	21	44	751	35294	36
36	CANTUAR NORTH	ROSERAY SAND	19680331	999.5	22	45	714	36008	36
40	Misc. # 4	R-S		844.1	23	47	676	36684	37
46	Misc. # 5	R-S		688.2	24	48	644	37328	38
51	ANTELOPE LAKE S	ROSERAY SAND	19640722	584.1	25	49	619	37947	38
56	Misc. # 6	R-S		580.2	26	50	618	38565	39
59	Misc. # 7	R-S		500.2	27	52	584	39149	39
66	ANTELOPE LAKE	ROSERAY SAND	19940611	469.9	28	54	569	39718	40
67	GULL LAKE	ROSERAY SAND	19940000	464.5	29	55	554	40272	41
73	ANTELOPE LAKE E.	ROSERAY SAND	19640116	457.3	30	56	548	40820	41
78	ANTELOPE LAKE N.	ROSERAY SAND	19950126	443.3	31	57	530	41350	42
					32	58	529	41879	42
					33	60	495	42374	43
					34	61	495	42869	43
					35	62	484	43353	44
					36	63	478	43831	44
					37	64	476	44307	45
					38	65	471	44778	45
					39	68	464	45242	46
					40	69	464	45706	46

The largest undiscovered pool in this play is expected to be the tenth ranked pool at 5.8 million m^3, a tenth the size of the largest pool at Battrum (Figure 5.8). The cross plot information suggests that the largest undiscovered pool would occupy 400 ha of area with an average net pay of seven metres (Figure 5.9).

Historical information indicates that only one percent of the total recovery comes from wells that have recovered less than five thousand m^3 each, which represents 35 percent of the total wells drilled in the play. However, 60 percent of the wells have produced over 10 thousand m^3 each capturing about half of the total production. The calculated average supply costs are in the economic range of $41-$44/m^3.

Compared with the GSC's 1998 report, the discovered heavy oil in place has increased from 150.3 to 171.9 million m^3 due to growth in existing pools and the inclusion of miscellaneous volumes. There was one new pool found between year-end 1994 and year-end 1997.

5.3 Resource Evaluation Overview

The Jurassic Zone has the smallest total volume of the three zones examined in this study mainly because of the limited distribution of its three geological plays in the WCSB. About 60 percent of

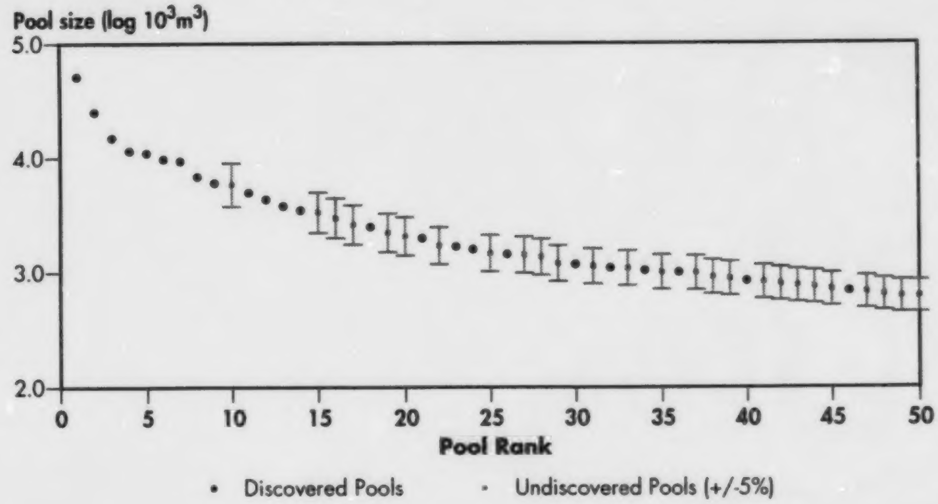
TABLE 5.6

Roseray-Success Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^{3}m^3)	Number of Pools	OIP (10^{3}m^3)
10 - 100 million	5	114018	0	0
1 - 10 million	16	61137	14	29357
100 - 1000 thousand	30	10498	158	44374
10 - 100 thousand	35	1471	687	22722
<10 thousand	10	53	611	2881
Total	**96**	**187176**	**1470**	**99333**

FIGURE 5.8

Pool Rank Plot – Roseray-Success



the estimated oil in place for this zone, 885 million m^3, has already been discovered (Figure 5.10), and half of that volume is in the Shaunavon play.

Over 80 percent of discovered reserves in this zone have already been produced (Figure 5.11). Although undiscovered pools account for 40 percent of the total oil in place, they account for only 20 percent of the recoverable volumes. This mainly reflects the pool size distribution, as 80 to 90 percent of the undiscovered pools have oil-in-place volumes of less than 100 thousand m^3. In comparison, only 40 to 50 percent of the discovered pools have oil-in-place volumes of less than 100 thousand m^3. It is anticipated that the bulk of future production will come from the

FIGURE 5.9

Cross Plot – Roseray-Success

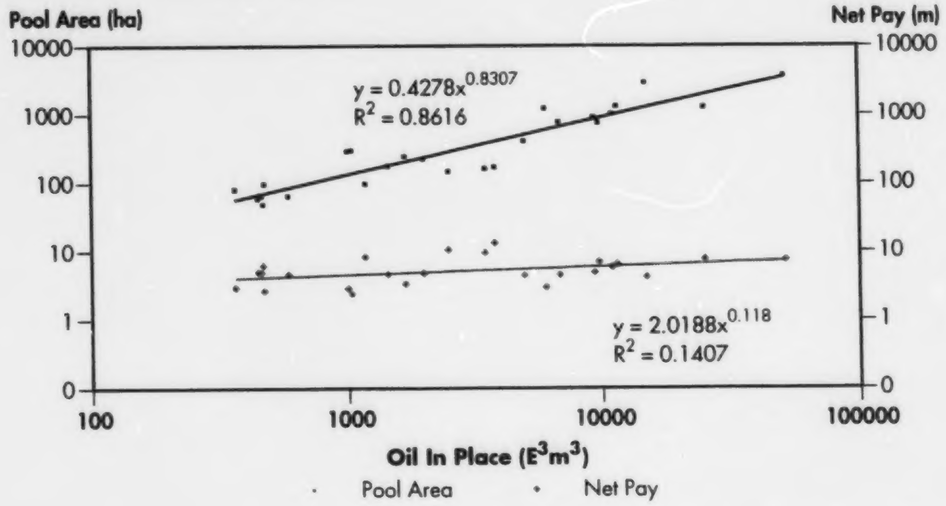


FIGURE 5.10

Initial Volume In Place – Jurassic

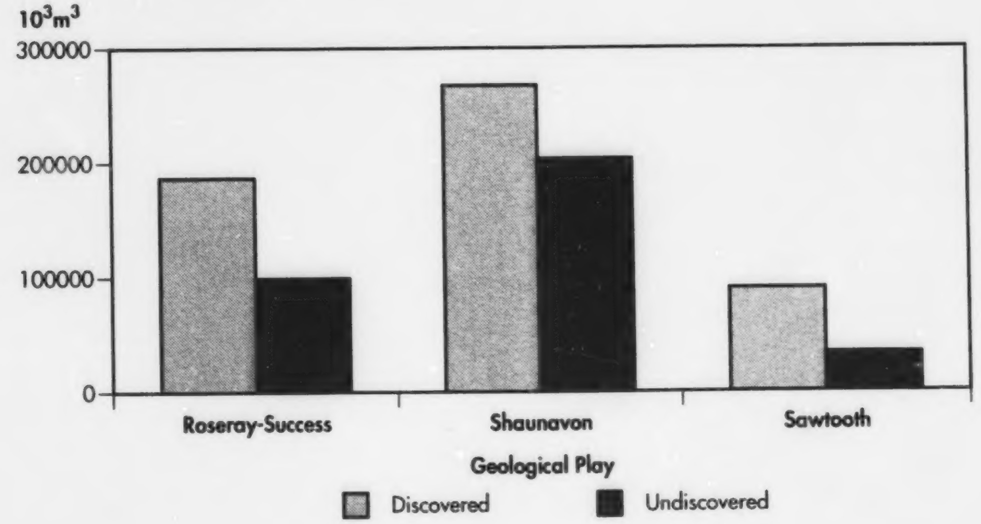
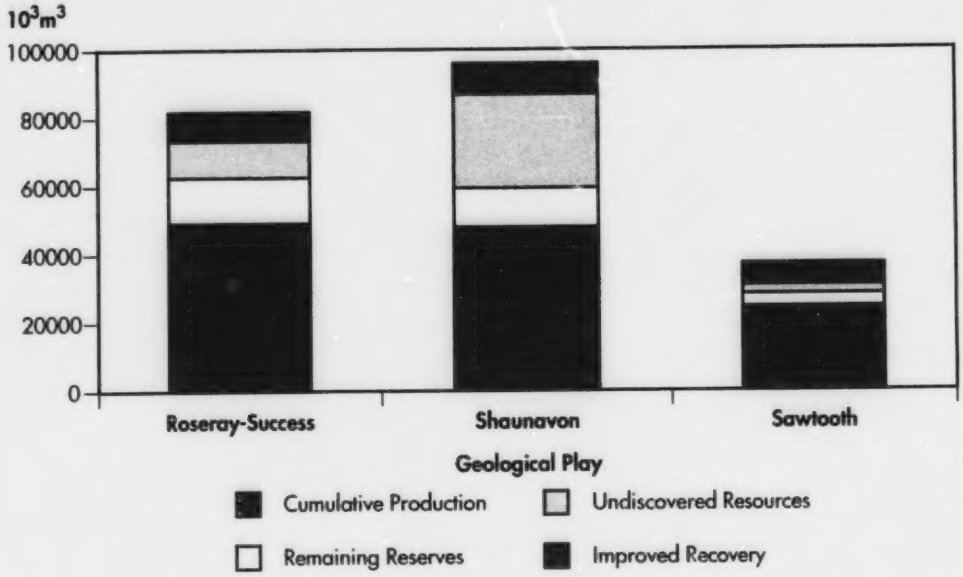


FIGURE 5.11

Recoverable Volumes – Jurassic



undiscovered pools. An additional 24.7 million m^3 of oil could be obtained through improvements in production practices.

The play-average recovery factors for the discovered pools in these three plays are 31, 22, and 33 percent, for the Sawtooth, Shaunavon, and Roseray-Success plays, respectively. These values are relatively high compared with other conventional heavy oil plays. The high average recovery factor for the Sawtooth play is due to the Grand Forks region pools, where there is a strong natural bottom-water drive present and estimated recoveries can reach 50 percent. It is anticipated that additional improved recovery from the discovered pools could increase the recovery by another two to seven percent. The recovery factors for the undiscovered pools are projected to range only from eight to 14 percent, less than one-half of the recovery values for the discovered pools. The lower recovery is projected since the bottom water drive responsible for the higher recoveries in discovered pools is not likely to be present in all areas.

5.3.1 Shaunavon Play

The Shaunavon play contains 53 percent of the oil in place, 40 percent of the reserves and two-thirds of undiscovered resources in the Jurassic Zone. The Shaunavon is projected to have 1,027 pools and only 131 pools have been discovered to date. Eighty percent of the total pools are projected to contain less than 100 thousand m^3 of oil in place and another 15 percent of the pools are projected to have oil-in-place volumes between 100 thousand m^3 and one million m^3 (Figure 5.12).

The total oil in place in the Shaunavon play is estimated to be 471 million m^3, and 57 percent of that, or 268 million m^3, has already been discovered. Pools with oil-in-place volumes of less than 1 million m^3 have a very minor role in the development of this play since only 14 percent of total oil in place is represented by this group of pools.

Two-thirds of the recoverable volumes are found in discovered pools. It appears that pools with more than 10 million m^3 are the most important pools in the overall economic development of this play. Approximately 60 percent of total recoverable volumes are contained in these pools, with 48 percent of total recoverable volumes in the seven largest discovered pools (Figure 5.13). Almost 80 percent of the recoverable volumes, and 26 percent of the total recoverable volume, will come from undiscovered pools containing more than one million m^3. This minimizes the importance of the contribution from the smaller undiscovered pools.

FIGURE 5.12

Pool Size Distribution – Shaunavon

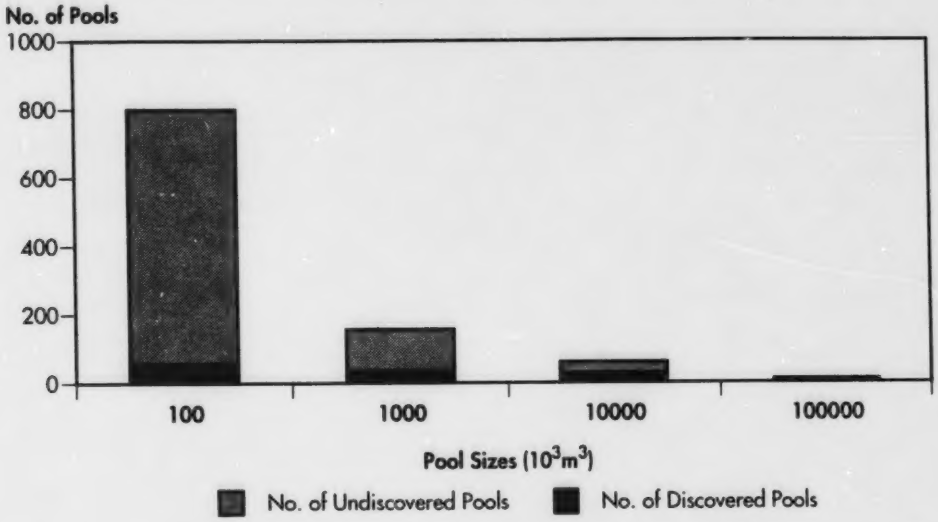
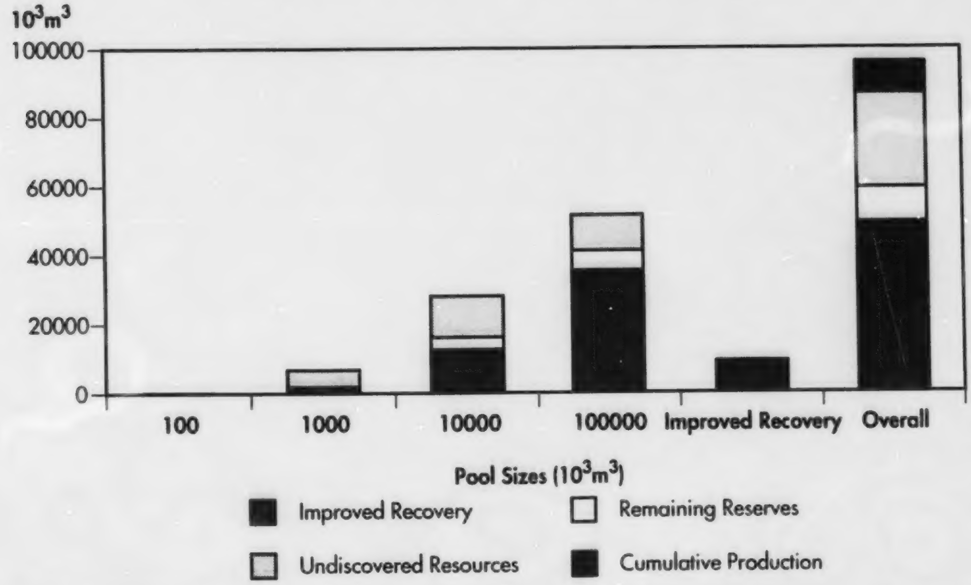


FIGURE 5.13

Recoverable Volumes by Source and Pool Size – Shaunavon



Small undiscovered pools play only a relatively minor role in the development of this play, as most of them are below the minimum pool size cut-off of 91 thousand m^3. The small pools that exceed the minimum size will recover 13 to 14 percent of the oil in place (Figure 5.14). The recovery factors for most discovered pools are in the 14 to 20 percent range; however, the recovery for the largest pools are in the 20 to 30 percent range.

The majority of future recovery is expected to come from the undiscovered pools in spite of their relatively low recovery factors since there are a large number of undiscovered pools and since the discovered pools have already produced a large portion of their recoverable reserves. However, an additional 9.1 million m^3 could be recovered from discovered Shaunavon pools through optimized production practices and initiation of additional enhanced recovery projects.

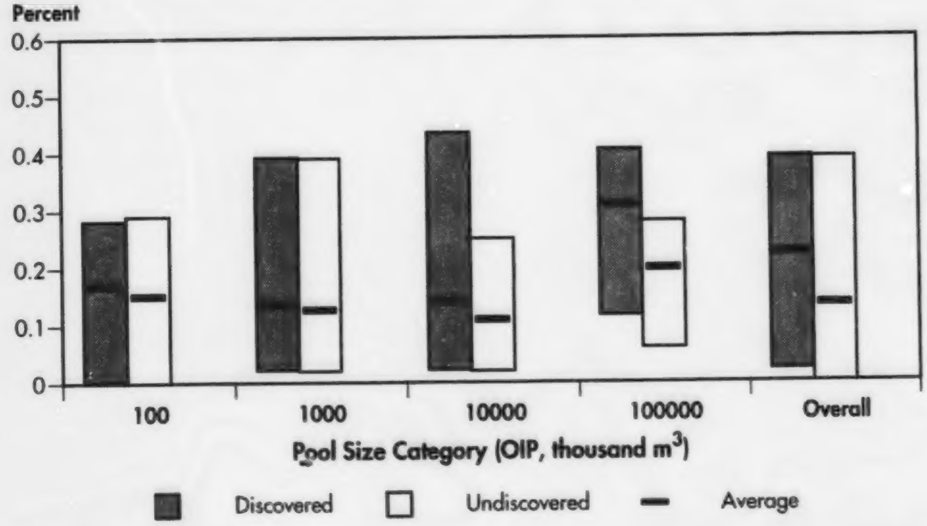
5.4 Summary

Since the last review by the GSC, the discovered oil-in-place volume of light and heavy oils for all plays in the Jurassic zones has increased from 532.9 to 888.7 million m^3, a growth of 67 percent. Heavy oil represents almost all of the NEB total oil-in-place volume. While a significant portion of the growth is due to the inclusion of the miscellaneous volumes, there has also been expansion of the existing pools and some new discoveries made. There were 32 new pools discovered between year-end 1994 and year-end 1997/98, primarily in the Sawtooth zone.

Although there are only three plays in this zone, the recoverable volumes are estimated to be greater than those of the Carboniferous zone (Table 5.7). It is estimated that 60 percent of the oil in place has been discovered, and that the remaining oil in place will be distributed in a large number of smaller pools. Due to its reservoir properties and the presence of bottom water, the average recovery factor for the discovered pools of 27 percent is relatively high compared with the other conventional heavy oil plays. However, the average recovery factor for the larger number of small undiscovered pools is expected to be closer to 12 percent. The combined recovery for the Jurassic zone, both discovered and undiscovered pools, will be approximately 22 percent using

FIGURE 5.14

Recovery Factors – Shaunavon



current production practices. It is estimated that an additional 2.6 percent could be recovered through improved recovery techniques.

The Board's analysis of the heavy oil pools indicates that there is a significant amount of heavy oil left to be found in these Jurassic plays in the provinces of Alberta and Saskatchewan. For the most part, the undiscovered pools will be smaller than the pools already discovered, but there are a few large pools left to be found. These large undiscovered pools may require development of a new exploration strategy, especially given the larger area for the Shaunavon play. As well, some pools may already be found but not yet recognized. Large pools may also result from the amalgamation of a number of smaller recognized or miscellaneous pools, following aggressive pool extension drilling.

TABLE 5.7

Resources of Jurassic Plays ($10^6 m^3$)

Play	Discovered		Undiscovered	
	Oil in Place	**Recoverable**	**Oil In Place**	**Recoverable**
Sawtooth	90.2	28.1	33.5	2.7
Shaunavon	267.7	57.8	203.4	27.5
Roseray-Success	187.2	64.0	99.3	10.8
Total	**545.1**	**149.9**	**336.2**	**41.0**

6. Cretaceous Zone Play Results

6.1 Geological Overview

The Mannville Group was deposited as a clastic wedge east of the mountain ranges. This wedge varies in thickness from 700 metres in the west to zero in the east. The stratigraphy changes within each of the regions shown on the play map; generally it consists of a lower transgressive sequence capped by an upper regressive sequence. The Board has assessed the heavy oil potential in the Central and Southern Alberta, Lloydminster and Saskatchewan Regions. For the minor amounts of heavy oil in the Northwest Alberta and British Columbia Region, the Board adopted the estimates from the GSC, while the Athabasca Region which contains oil sands was not evaluated in this report. The effective northern limit for conventional heavy oil in the Lloydminster Region is Township 53, where the Cold Lake Oil Sands Area begins in Alberta.

The lower transgressive sequence consists of the deposits of the Lower Mannville Group. These deposits represent continental deposits of alluvial fans and braided streams in the Cadomin Formation, through fluvial and lacustrine deposits of the Basal Quartz, Ellerslie, Ostracod, Gething, Cutbank, Sunburst, Dina, and McMurray Formations that grade upwards into marginal marine sequences.

A major change of the depositional style occurred at the end of the Lower Mannville deposition, when there was a switch to the mainly regressive sequences of the Upper Mannville Group. The progradational shoreline sand deposits of the Glauconitic and Clearwater Formations reflect that change. These were followed by the northward progradations of the Spirit River, Grand Rapids and Upper Mannville Groups.

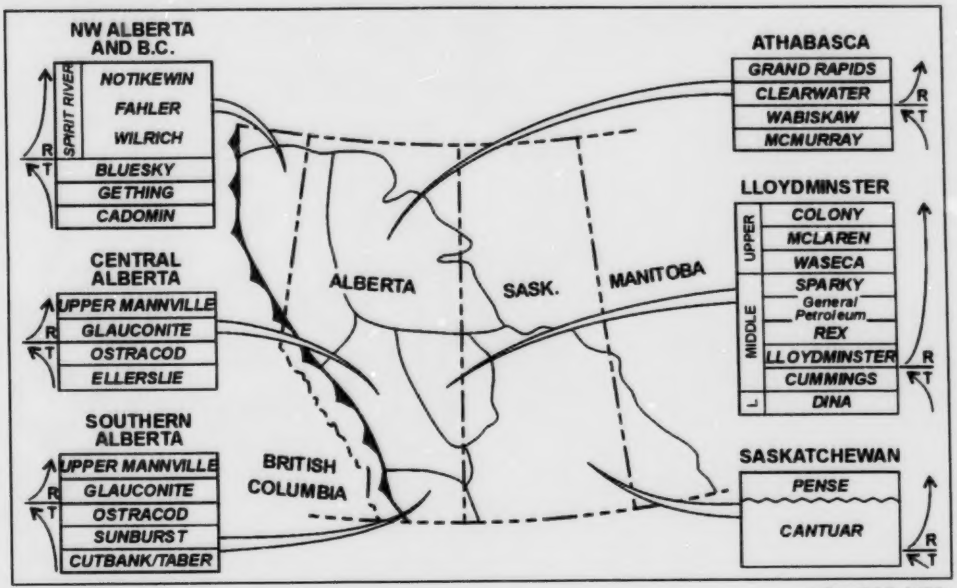
6.2 Central and Southern Alberta Regions

6.2.1 Lower Mannville Heavy Oil Play

This play includes all of the Lower Mannville Formation heavy oil pools except for the separated Ostracod play discussed in the Central Region. The heavy oil pools, as defined by the EUB, include the Ellerslie and Basal Quartz deposits of Central Alberta and the Cutbank/Taber, Sunburst, and Ostracod Formations in Southern Alberta (Figure 6.1). The primary controlling factor for these reservoirs is the pre-Cretaceous unconformity surface. The Basal Quartz, Sunburst and Cutbank/Taber deposits are found within valleys on that surface; the Ellerslie Formation is also found in these valleys. Ellerslie deposition completely filled these valleys and spread laterally to cover the pre-existing topographic highs. The Ellerslie Formation grades upwards into the marginally marine (lacustrine) deposits of the Ostracod. Traps are formed both stratigraphically where the sands or porosity pinches out, and structurally by drape over previous topographic highs. Source rocks are believed to be older shale or carbonate sequences.

FIGURE 6.1

Cretaceous Play Areas


NW ALBERTA AND B.C.
SPIRIT RIVER
NOTIKEWIN
FAHLER
WILRICH
BLUESKY
GETHING
CADOMIN
R
T
CENTRAL ALBERTA
UPPER MANNVILLE
GLAUCONITE
OSTRACOD
ELLERSLIE
R
T
SOUTHERN ALBERTA
UPPER MANNVILLE
GLAUCONITE
OSTRACOD
SUNBURST
CUTBANK/TABER
R
T
ALBERTA
SASK.
MANITOBA
BRITISH COLUMBIA
ATHABASCA
GRAND RAPIDS
CLEARWATER
WABISKAW
MCMURRAY
R
T
LLOYDMINSTER
UPPER
MIDDLE
L
COLONY
MCLAREN
WASECA
SPARKY
General Petroleum
REX
LLOYDMINSTER
CUMMINGS
DINA
R
T
SASKATCHEWAN
PENSE
CANTUAR
R
T

(after GSC 1998)

The Board's assessment is based on a discovered oil-in-place estimate of 232.3 million m^3, contained in 476 designated pools (Table 6.1). This was supplemented by the addition of 240 identified potential pools, containing 5.8 million m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model (Table 6.2). There were no identified miscellaneous pools for this play. The model projects an additional 4,875 undiscovered pools exist. They are expected to contain 126.1 million m^3 of oil in place. The projected pools include 236 pools that are expected to contain more than 100 thousand m^3 of oil in place each. These capture 32 percent of the total undiscovered potential. The total resource estimate is 364.1 million m^3, of which 36 percent was undiscovered at year-end 1998. This is a play where having two or more undiscovered pools with less than 100 thousand m^3 in the same section could allow some development of those smaller pools through the sharing of surface facilities. It is reasonable to expect some portion of the 10 to 100 thousand m^3 pool size class to be developed.

The largest undiscovered pool in this play is the 42nd ranked pool at 1.2 million m^3 oil in place, much smaller than the Bantry Mannville A pool with its in-place resource of 22.8 million m^3 (Figure 6.2). The cross plot information suggests that the largest undiscovered pool would occupy about 300 ha with an average net pay of seven metres (Figure 6.3). Industry indicated that the estimates for the largest undiscovered pool and the undiscovered resource were too small. The Board notes that this play is located in heavily drilled areas which restricts the possible pool size. A future assessment, with updated information, may yield higher values.

Approximately 70 percent of the wells in this play have produced less than five thousand m^3 each and 80 percent of the wells have produced less than 10 thousand m^3 each. Together, these two groups capture less than 17 percent of the play's total production. Wells in the 10 to 20 thousand m^3 of production category, and wells with production of more than 20 thousand m^3 captured the bulk of the production. The average supply costs for this play are estimated to be in the range of \$81-\$93/m^3 (Supply costs are discussed in Chapter 7).

TABLE 6.1

Lower Mannville – Heavy, Central and Southern Alberta

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
476	232,304	51,146	42,739	8,407	5115	131,839	10,280	5,591	364,144	61,426	18,687

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Alberta	51,146		Ave	Min	Max	Ave	Min	Max	1937
			1024	736	2454	3.9	0.6	46.6	
Porosity (fraction)			**Area (ha)**			**Oil Saturation (fraction)**			**% Undiscovered**
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	36
0.19	0.08	0.33	105	2	4048	0.63	0.3	0.94	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field · Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	BANTRY	MANNVILLE A	19471013	22800.0	1	42	1184	1184	1
2	GRAND FORKS	LOWER MANNVILLE D	19680206	16210.0	2	52	870	2054	2
3	TABER SOUTH	MANNVILLE A	19630907	14080.0	3	59	696	2750	2
4	HORSEFLY LAKE	MANNVILLE	19631019	9671.0	4	64	629	3379	3
5	TABER	TABER N	19830830	7732.0	5	78	512	3891	3
6	CESSFORD	MANNVILLE Y	19510000	7362.0	6	81	494	4385	3
7	TABER SOUTH	TABER B	19791008	4684.0	7	86	465	4850	4
8	CHIN COULEE	BASAL MANNVILLE A	19600209	4337.0	8	94	442	5292	4
9	GRAND FORKS	LOWER MANN K	19731212	4002.0	9	96	421	5713	4
10	BANTRY	MANNVILLE D	19630000	3986.0	10	99	403	6116	5
11	HAYS	LOWER MANNVILLE A	19641105	3604.0	11	103	388	6504	5
12	PRINCESS	BASAL MANNVILLE A	19630000	3058.0	12	105	385	6889	5
13	ALDERSON	LOWER MANNVILLE B	19640519	3029.0	13	112	360	7249	5
14	TABER	TABER Q	19870301	2864.0	14	113	357	7606	6
15	TABER NORTH	TABER C	19740315	2862.0	15	116	342	7948	6
16	ALDERSON	LWR MANNVILLE TT	19910313	2747.0	16	120	331	8279	6
17	CESSFORD	MANNVILLE Z	19510000	2454.0	17	124	327	8606	7
18	ALDERSON	LWR MANNVILLE QQ	19820417	2249.0	18	126	320	8926	7
19	TABER NORTH	TABER O	19830628	2171.0	19	128	314	9240	7
20	BANTRY	MANNVILLE FF	19680000	2159.0	20	132	308	9548	7
21	WRENTHAM	LWR MANNVILLE C	19670722	2127.0	21	134	304	9852	7
22	ALDERSON	LWR MANNVILLE D4D	19950723	1997.0	22	136	301	10153	8
23	TABER NORTH	TABER A	19660918	1950.0	23	138	299	10452	8
24	HAYS	LOWER MANNVILLE O	19830712	1802.0	24	140	295	10747	8
25	BANTRY	MANNVILLE B	19600722	1761.0	25	143	291	11038	8
26	COUNTESS	LOWER MANNVILLE X	19940221	1704.0	26	148	283	11321	9
27	SUFFIELD	LOWER MANNVILLE P	19440410	1659.0	27	150	281	11602	9
28	TABER	TABER I	19900922	1588.0	28	153	277	11879	9
29	STROME	ELLERSLIE D	19780826	1541.0	29	156	274	12153	9
30	ALDERSON	LWR MANNVILLE D3D	19930104	1539.0	30	158	269	12422	9
31	TABER SOUTH-EAST	MANNVILLE A	19630000	1462.0	31	159	267	12689	10
32	TABER NORTH	TABER D	19760712	1450.0	32	162	264	12953	10
33	TABER	TABER L	19931011	1379.0	33	164	259	13212	10
34	BANTRY	MANNVILLE F	19630000	1350.0	34	166	256	13468	10
35	ALDERSON	LWR MANNVILLE F	19710630	1348.0	35	167	253	13721	10
36	ALDERSON	LWR MANNVILLE H2H	19711202	1348.0	36	169	249	13970	11
37	TABER	TABER M	19790715	1315.0	37	171	244	14214	11
38	WRENTHAM	LWR MANNVILLE B	19670102	1294.0	38	174	240	14454	11
39	RETLAW	MANNVILLE I	19641016	1270.0	39	176	235	14689	11
40	TABER NORTH	TABER K	19830000	1242.0	40	178	233	14922	11

Compared with the GSC's 1998 report, the discovered oil in place for both light and heavy oils has increased from 350.3 to 536.9 million m^3 due to new discoveries, growth in existing pools and the reassignment of some pools to their proper play designation after splitting of the commingled pools. There were 175 new pools found between year-end 1994 and year-end 1998. This growth can be attributed primarily to the extensive oil drilling activity that took place during 1996 and 1997.

6.2.2 Upper Mannville Heavy Oil Play

This mature play is defined to include all of the heavy oil pools in the Upper Mannville Group in Southern and Central Alberta, as well as the Glauconitic pools in Southern Alberta (Figure 6.1).

TABLE 6.2

Lower Mannville Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	**Number of Pools**	**OIP (10^3m^3)**	**Number of Pools**	**OIP (10^3m^3)**
10 - 100 million	3	53090	0	0
1 - 10 million	44	107957	1	1184
100 - 1000 thousand	232	60798	235	41020
10 - 100 thousand	372	15834	2529	73199
<10 thousand	65	394	2110	10668
Total	**716**	**238071**	**4875**	**126071**

FIGURE 6.2

Pool Rank Plot – Lower Mannville

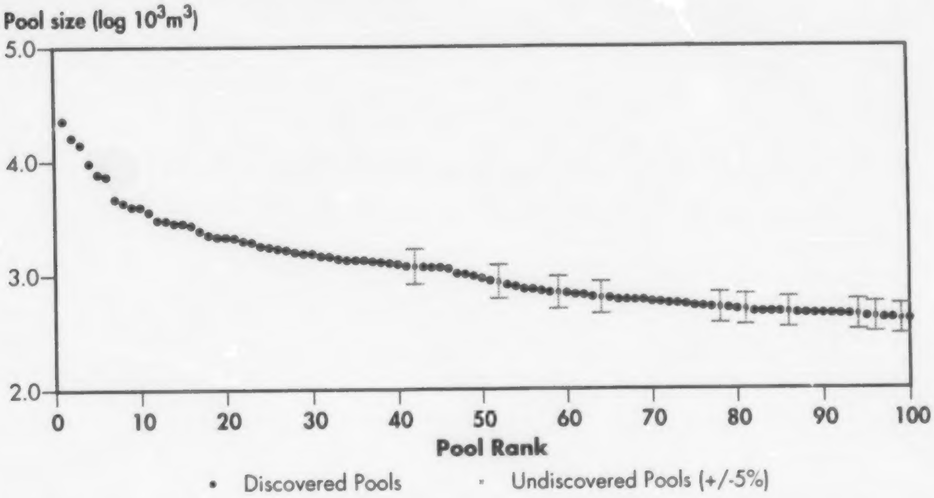
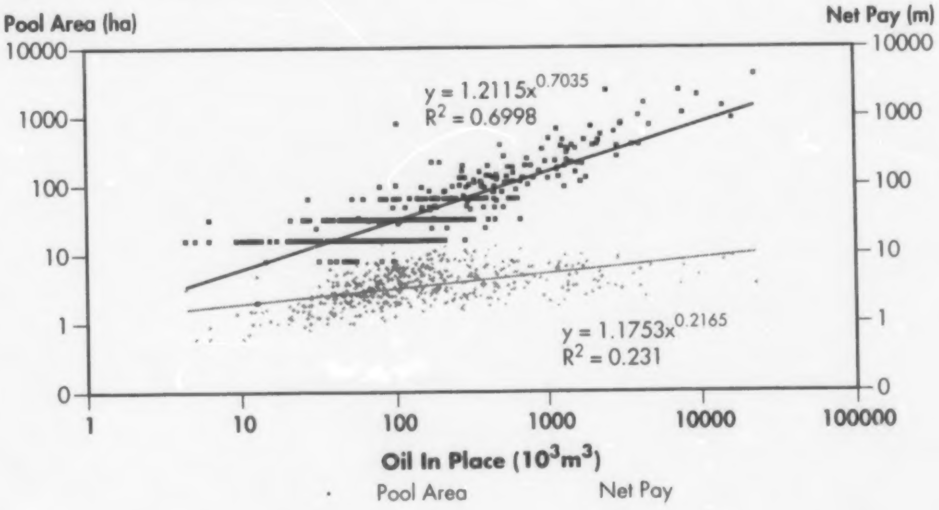


FIGURE 6.3

Cross Plot – Lower Mannville



Most reservoirs in these areas consist of fine-grained sandstones which can reach a thickness of 20 metres in fluvial valley fill settings. Traps result from a combination of lateral shale-out or structural drape over highs on the mid-Cretaceous unconformity. Source rocks are believed to be from underlying Mississippian sequences or from more deeply buried Cretaceous shales.

The Board's assessment is based on a discovered oil-in-place estimate of 313.8 million m^3, contained in 306 designated pools (Table 6.3). This was supplemented by the addition of 67 identified potential pools, containing 2.2 million m^3 of oil in place, in order to better define the

TABLE 6.3

Upper Mannville – Heavy, Central and Southern Alberta

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
306	313,819	66,630	48,650	17,980	3335	160,396	13,794	3,641	474,215	80,424	31,774

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Alberta	66,630		Ave	Min	Max	Ave	Min	Max	1942
			1025	600	1221	4.2	0.6	18	
Porosity (fraction)			**Area (ha)**			**Oil Saturation (fraction)**			**% Undiscovered**
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	34
0.2	0.05	0.33	126	4	4062	0.69	0.27	0.9	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	SUFFIELD	UPPER MANNVILLE A	19760815	49960.0	1	33	1995	1995	1
2	SUFFIELD	UPPER MANNVILLE J	19660000	35300.0	2	38	1819	3814	2
3	SUFFIELD	UPPER MANNVILLE FF	19861219	13040.0	3	51	1340	5154	3
4	COUNTESS	UPPER MANNVILLE D	19670803	12950.0	4	55	1238	6392	4
5	TABER NORTH	GLAUCONITIC A	19790929	9303.0	5	62	1058	7450	5
6	JENNER	UPPER MANNVILLE O	19521016	7970.0	6	64	982	8432	5
7	TABER SOUTH	MANNVILLE B	19630831	7277.0	7	66	936	9368	6
8	TABER	GLAUCONITIC K	19420618	6172.0	8	69	870	10238	6
9	JENNER	UPPER MANNVILLE F	19650709	6025.0	9	75	783	11021	7
10	COUNTESS	UPPER MANNVILLE H	19680000	5725.0	10	78	768	11789	7
11	SUFFIELD	UPPER MANNVILLE D	19761217	5434.0	11	81	707	12496	8
12	JENNER	UPPER MANNVILLE E	19630000	5380.0	12	82	672	13168	8
13	BOW ISLAND	GLAUCONITIC A	19850131	5230.0	13	84	627	13795	9
14	ATLEE-BUFFALO	UPPER MANNVILLE G	19800920	5065.0	14	85	604	14399	9
15	LATHOM	UPPER MANNVILLE A	19680603	4516.0	15	86	580	14979	9
16	COUNTESS	UPPER MANNVILLE B	19650000	4412.0	16	89	559	15538	10
17	JENNER	UPPER MANNVILLE OO	19941022	4197.0	17	91	547	16085	10
18	ATLEE-BUFFALO	UPPER MANNVILLE F	19741026	3803.0	18	93	514	16599	10
19	LITTLE BOW	UPPER MANNVILLE I	19741015	3691.0	19	96	500	17099	11
20	SUFFIELD	UPPER MANNVILLE U	19800224	3264.0	20	98	490	17589	11
21	GRAND FORKS	UPPER MANNVILLE B	19710000	3111.0	21	99	483	18072	11
22	BADGER	UPPER MANNVILLE B	19800505	3014.0	22	102	459	18531	12
23	COUNTESS	UPPER MANNVILLE YY	19900000	2699.0	23	104	455	18986	12
24	TABER NORTH	GLAUCONITIC C	19800921	2653.0	24	106	447	19433	12
25	COUNTESS	UPPER MANNVILLE O	19730411	2541.0	25	107	439	19872	12
26	LITTLE BOW	UPPER MANNVILLE W	19830219	2455.0	26	109	435	20307	13
27	LITTLE BOW	UPPER MANNVILLE S	19780909	2400.0	27	110	429	20736	13
28	RETLAW	MANNVILLE LL	19790000	2397.0	28	111	422	21158	13
29	SUFFIELD	UPPER MANNVILLE N	19780213	2291.0	29	112	417	21575	13
30	COUNTESS	UPPER MANNVILLE PP	19840000	2160.0	30	113	414	21989	14
31	TABER NORTH	GLAUCONITIC E	19780818	2157.0	31	118	408	22397	14
32	LITTLE BOW	UPPER MANNVILLE G	19700910	2061.0	32	120	406	22803	14
34	COUNTESS	UPPER MANNVILLE F	19540000	1882.0	33	122	401	23204	14
35	TABER	GLAUCONITIC F	19640313	1867.0	34	123	397	23601	15
36	RETLAW	MANNVILLE V	19710118	1860.0	35	125	392	23993	15
37	ALDERSON	UPPER MANNVILLE Z	19791107	1858.0	36	128	390	24383	15
39	JENNER	UPPER MANNVILLE X	19840521	1772.0	37	130	382	24765	15
40	JENNER	UPPER MANNVILLE M	19710328	1768.0	38	132	380	25145	16
41	NORRIS	UPPER MANNVILLE H	19791118	1752.0	39	133	376	25521	16
42	LITTLE BOW	UPPER MANNVILLE U	19821127	1701.0	40	135	372	25893	16

play's distribution in the geo-anchored model (Table 6.4). There were no identified miscellaneous pools for this play. The model projects an additional 3,268 undiscovered pools exist. They are expected to contain 158.2 million m^3 of oil in place. The projected pools include 380 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture about half of the total undiscovered potential. The total resource estimate is 474.2 million m^3, of which 34 percent was undiscovered at year-end 1998.

The largest undiscovered pool would be the 33rd ranked pool and is expected to contain about 2.0 million m^3, much smaller than the largest discovered pool, the Suffield Upper Mannville A pool, which contains almost 50 million m^3 (Figure 6.4). The cross plot information suggests that the largest undiscovered pool would occupy almost 200 ha with about six metres of average net pay (Figure 6.5). Industry indicated that the largest undiscovered pool should be larger than the 2.0 million m^3 projected in this report. The Board notes that this play is located in heavily drilled areas which restricts the possible pool size. A future assessment, with updated information, may yield higher values.

Approximately 65 percent of the wells produced less than five thousand m^3 each, capturing less than 18 percent of total production. Twenty percent of the wells produced over 10 thousand m^3 each and seven percent of the wells produced over 20 thousand m^3 each. These two groups of

TABLE 6.4

Upper Mannville Play - Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	**Number of Pools**	**OIP (10^3m^3)**	**Number of Pools**	**OIP (10^3m^3)**
10 - 100 million	4	111250	0	0
1 - 10 million	54	155440	5	7450
100 - 1000 thousand	149	42306	375	75032
10 - 100 thousand	158	6984	2114	72642
<10 thousand	8	41	774	3069
Total	**373**	**316020**	**3268**	**158194**

FIGURE 6.4

Pool Rank Plot - Upper Mannville

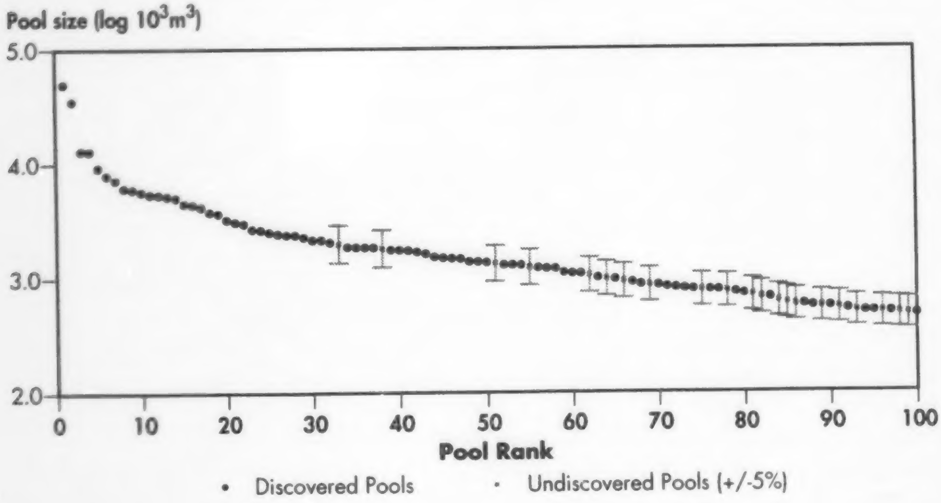
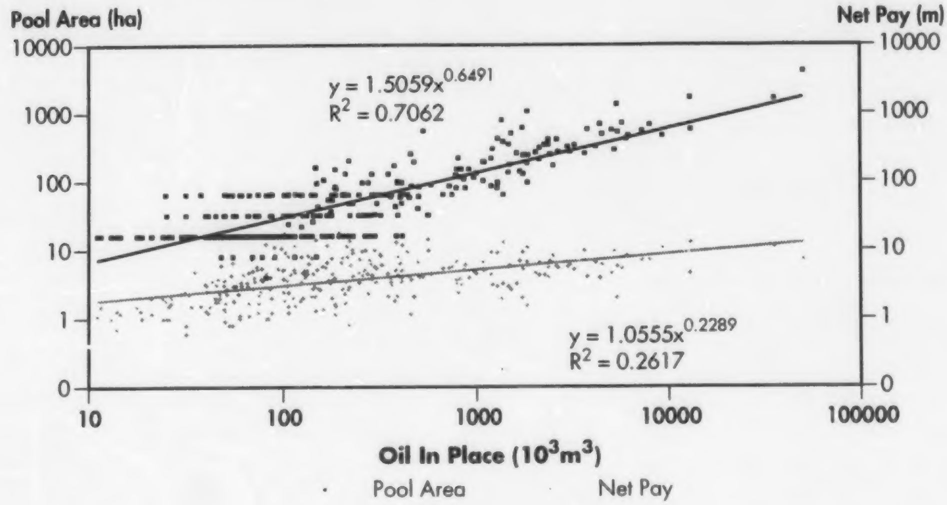


FIGURE 6.5

Cross Plot – Upper Mannville



wells each captured about 35 percent of the total recovery to date. The performance of the wells that produced 10 to 20 thousand m^3 played an important role in the overall cost structure of this play, because they help to offset the higher costs of the lower productivity wells. The average supply costs are estimated to be in the range of \$82-\$96/m^3.

Compared with the GSC's 1998 report, the discovered oil in place for both light and heavy oils has decreased from 591.3 to 417.6 million m^3 mainly as a result of the reassignment of pools to their proper play when commingled pools were split. The significant growth in some of the other plays is partly due to that splitting. In total, there was some actual growth in the oil-in-place volume because of new discoveries and expansion of existing pools, since there were 70 new pools found between year-end 1994 and year-end 1998.

6.3 Southern Alberta Region

6.3.1 Detrital Play

This play is defined to include all the oil pools in the Detrital Formation of Alberta and the Deville Formation of Saskatchewan. This poorly understood play consists of weathered products lying directly on the Paleozoic rocks and separated from the Mannville Group sediments by an unconformity. The reason for its patchy distribution has yet to be determined. Whether it results from the pre-Mannville erosion or from non-deposition is not known. The Detrital occurs locally as either a low on the unconformity surface or as a high standing region. Deposits consist of sandstone, mudstone and chert-pebble conglomerates.

The Board's assessment is based on a discovered oil-in-place estimate of 3.2 million m^3, contained in 28 designated pools (Table 6.5). This was supplemented by the addition of 49 identified potential pools, containing 2.4 million m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model (Table 6.6). There were no identified miscellaneous pools for this play. The model projects an additional 634 undiscovered pools exist. They are expected to contain 43.3 million m^3 of oil in place. The projected pools include 125 pools that are expected to

TABLE 6.5

Detrital – Heavy, Alberta

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
thousand cubic metres					thousand cubic metres			thousand cubic metres			
28	3,189	152	66	86	683	45,734	2,009	711	48,922	2,161	2,095

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Alberta	152		Ave	Min	Max	Ave	Min	Max	1963
			993	689	1129	4.5	1.5	10	
Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	94
0.22	0.15	0.33	29	16	114	0.6	0.5	0.76	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
4	CESSFORD	DETRITAL F	19941003	293.0	1	1	336	336	1
12	HEATHDALE	DETRITAL A	19880915	248.0	2	2	321	657	1
22	SUPERBA	DETRITAL A	19810806	213.0	3	3	309	966	2
28	CESSFORD	MANNVILLE T2T	19870401	203.0	4	5	290	1256	3
37	PRINCESS (poff)			192.8	5	6	282	1538	3
45	HEATHDALE	DETRITAL C	19941124	185.0	6	7	275	1813	4
50	ALDERSON	DETRITAL A	19830301	178.0	7	8	269	2082	5
					8	9	264	2346	5
					9	10	259	2605	6
					10	11	253	2858	6
					11	13	244	3102	7
					12	14	239	3341	7
					13	15	235	3576	8
					14	16	231	3807	8
					15	17	227	4034	9
					16	18	224	4258	9
					17	19	220	4478	10
					18	20	215	4693	10
					19	21	213	4906	11
					20	23	211	5117	11
					21	24	209	5326	12
					22	25	208	5534	12
					23	26	206	5740	13
					24	27	205	5945	13
					25	29	202	6147	13
					26	30	201	6348	14
					27	31	200	6548	14
					28	32	198	6746	15
					29	33	197	6943	15
					30	34	196	7139	16
					31	35	195	7334	16
					32	36	194	7528	16
					33	38	192	7720	17
					34	39	191	7911	17
					35	40	190	8101	18
					36	41	188	8289	18
					37	42	187	8476	19
					38	43	186	8662	19
					39	44	185	8847	19
					40	46	183	9030	20

contain more than 100 thousand m^3 of oil in place each, these capture about half of the total undiscovered potential. The total resource estimate is 48.9 million m^3, of which 94 percent was undiscovered at year-end 1998.

The largest three pools in this play are considered to be undiscovered, containing 336, 321 and 309 thousand m^3 of oil in place, respectively. The largest discovered pool is the Cessford Detrital F pool at 293 thousand m^3 (Figure 6.6). The cross plot information suggests that the largest undiscovered pool would occupy about 500 ha with an average net pay of about eight metres (Figure 6.7). Industry agreed that the largest pool was still undiscovered but suggested that the overall resource estimate was too large. The economic analysis should reduce the developable

TABLE 6.6

Detrital Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^3m^3)	Number of Pools	OIP (10^3m^3)
10 - 100 million	0	0	0	0
1 - 10 million	0	0	0	0
100 - 1000 thousand	18	2902	125	20446
10 - 100 thousand	57	2675	490	22721
<10 thousand	2	16	19	162
Total	**77**	**5594**	**634**	**43329**

FIGURE 6.6

Pool Rank Plot – Detrital

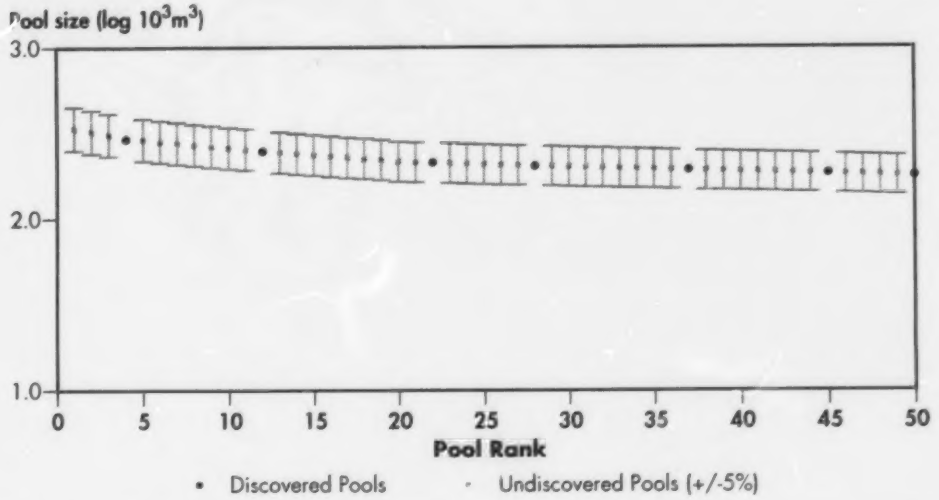
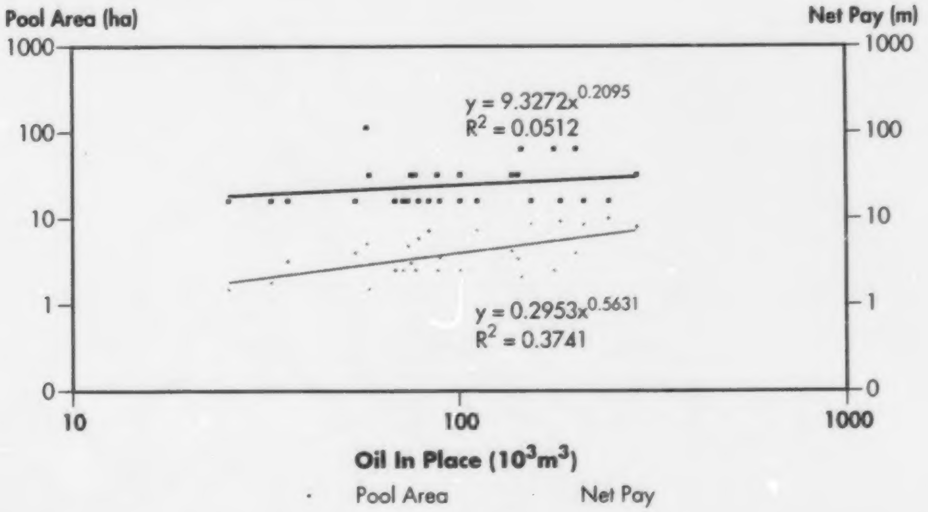


FIGURE 6.7

Cross Plot – Detrital



resources to a more acceptable level. This play needs to be studied in more detail in order to be a prime exploration target. Even then, it is debatable whether or not the total potential and expected pool sizes justify the required exploration and development effort.

About 85 percent of the wells have produced less than five thousand m^3 each and 95 percent of the wells have produced less than 10 thousand m^3 each. Together, these two groups account for approximately 50 percent of the total production in this play. There were very few wells in the range of 10 to 30 thousand m^3, but they account for the other half of the production. These wells have an important role in lowering the overall cost structure of this play. The average supply costs are estimated to be in the range of \$81-\$93/m^3.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has decreased from 16.3 to 6.0 million m^3 . While there were six new discoveries made between year-end 1994 and year-end 1998, the SEM redesignated two large pools to the Roseray-Success play and the EUB made large negative revisions to two pools, both subsequent to the GSC's analysis.

6.4 Central Alberta Region

6.4.1 Ostracod Play

This play includes all the oil pools in the Ostracod Formation in the Central Alberta Region (Figure 6.1). The Ostracod Formation consists of thin calcareous mudstones with interbedded limestone or sandstones, interpreted to have been deposited in shallow brackish water bays and lagoons or in freshwater lakes. Reservoir units are generally thin sandstone bodies possibly related to Lower Glauconitic sequences or valley fill deposits. Most traps are formed by lateral and vertical pinchout of sand into the mudstones, while the remainder result from structural drape.

The Board's assessment is based on a discovered oil-in-place estimate of 2.9 million m^3, contained in 17 designated pools (Table 6.7). This was supplemented by the addition of six identified potential pools, containing 112 thousand m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model (Table 6.8). There were no identified miscellaneous pools for this play. The model projects an additional 240 undiscovered pools exist. They are expected to contain 13.9 million m^3 of oil in place. The projected pools include 56 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture about three-quarters of the total undiscovered potential. The total resource estimate is 16.9 million m^3, of which 83 percent was undiscovered at year-end 1998.

The largest undiscovered pool, containing 498 thousand m^3 of oil in place, is expected to be the first ranked pool in the play, but would only be marginally larger than the Tomahawk Ostracod G pool which contains 456 thousand m^3 (Figure 6.8). The cross plot information suggests that the largest undiscovered pool would occupy about 100 ha with five metres of average net pay (Figure 6.9). Industry has supported the projection that the largest pool is still undiscovered, but indicated that the total undiscovered resource was too large. The analysis of the reservoir properties data and the supply cost analysis reduces the developable undiscovered potential to a more acceptable level.

Approximately 90 percent of the wells have produced less than five thousand m^3 each and 95 percent of the wells produced less than 10 thousand m^3 each. These wells account for approximately 22 percent and 40 percent of the total production, respectively. The few wells that produced over 10 thousand m^3 account for almost 40 percent of the total production and help to reduce the relatively high costs of this play. The average supply costs are estimated to be in the range of \$95-\$111/m^3.

TABLE 6.7

Ostracod – Heavy, Central Alberta

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
thousand cubic metres					thousand cubic metres			thousand cubic metres			
17	2,897	251	183	68	246	14,024	1,572	263	16,921	1,823	1,640

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)		Depth from KB (metres)			Net Pay (metres)			Discovery Yr
		Ave	Min	Max	Ave	Min	Max	1958
Alberta	251	1215	1005	1778	3.7	1	11.8	

Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	83
0.21	0.16	0.25	61	16	229	0.64	0.48	0.9	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
2	TOMAHAWK	OSTRACOD G	19900803	456.0	1	1	490	490	3
6	BANTRY	MANNVILLE QQ	19910925	311.0	2	3	400	890	6
8	ALEXIS	OSTRACOD B	19700625	296.0	3	4	369	1259	9
17	BANTRY	MANNVILLE WW	19631013	200.0	4	5	344	1603	11
19	BIGORAY	OSTRACOD J	19950108	193.0	5	7	308	1911	14
29	BANTRY	MANNVILLE II	19850228	169.0	6	9	295	2206	16
30	COUNTESS	OSTRACOD D	19850313	169.0	7	10	270	2476	18
33	BANTRY	MANNVILLE UU	19630826	168.0	8	11	258	2734	19
39	BANTRY	MANNVILLE FFF	19950511	164.0	9	12	245	2979	21
43	ALEXIS	OSTRACOD A	19681012	159.0	10	13	233	3212	23
50	ENTWISTLE	OSTRACOD A	19971113	143.0	11	14	223	3435	24
59	ATIM	OSTRACOD A	19890911	116.0	12	15	207	3642	26
					13	16	201	3843	27
					14	18	196	4039	29
					15	20	188	4227	30
					16	21	185	4412	31
					17	22	182	4594	33
					18	23	179	4773	34
					19	24	177	4950	35
					20	25	172	5122	37
					21	26	171	5293	38
					22	27	170	5463	39
					23	28	169	5632	40
					24	31	169	5801	41
					25	32	168	5969	43
					26	34	168	6137	44
					27	35	167	6304	45
					28	36	166	6470	46
					29	37	165	6635	47
					30	38	164	6799	48
					31	40	163	6962	50
					32	41	161	7123	51
					33	42	159	7282	52
					34	44	158	7440	53
					35	45	156	7596	54
					36	46	152	7748	55
					37	47	150	7898	56
					38	48	147	8045	57
					39	49	145	8190	58
					40	51	142	8332	59

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 23.5 to 26.7 million m^3 due to new discoveries, expansion of existing pools and the reassignment of some pools to their proper play designation after splitting of the commingled pools. There were eight new pools found between year-end 1994 and year-end 1998.

6.4.2 *Glauconitic Play*

The Glauconitic and Ostracod plays in the Central Alberta Region are distinguished from the Upper and Lower Mannville plays in the Southern and Central Regions by the absence of the Cummings-Moosebar-Bantry shales as distinctive marker beds (Figure 6.1). In areas where these shales are absent, the Lower Mannville becomes less continuous and may not be exposed to the

TABLE 6.8

Ostracod Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^3m^3)	Number of Pools	OIP (10^3m^3)
10 - 100 million	0	0	0	0
1 - 10 million	0	0	0	0
100 - 1000 thousand	13	2648	56	10194
10 - 100 thousand	7	342	90	3071
<10 thousand	3	19	94	647
Total	**23**	**3009**	**240**	**13912**

FIGURE 6.8

Pool Rank Plot – Ostracod

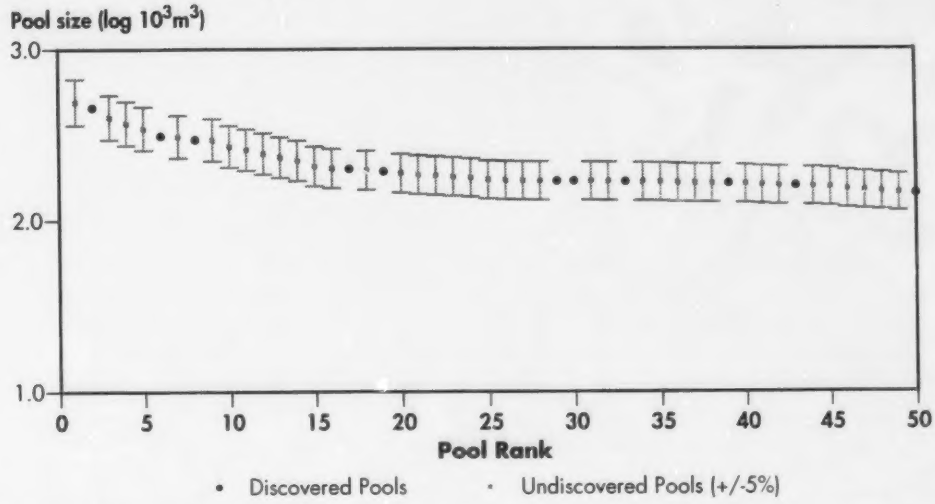
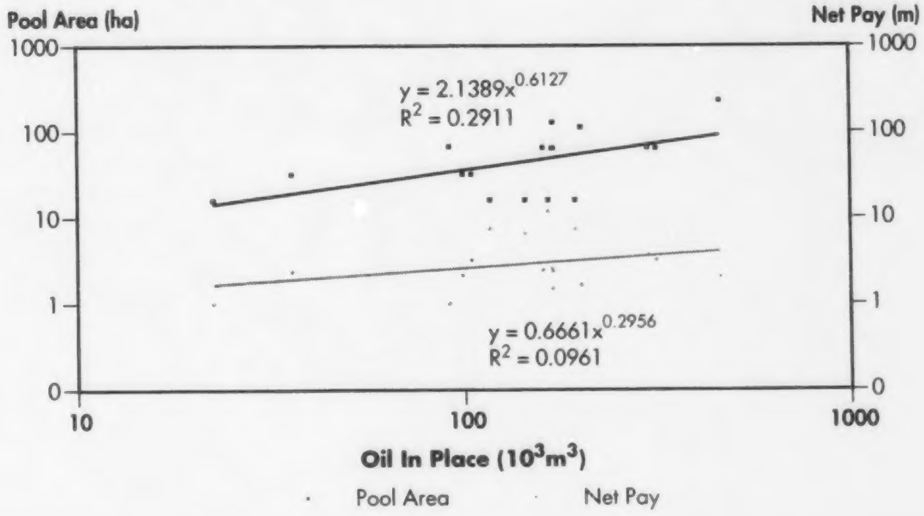


FIGURE 6.9

Cross Plot – Ostracod



hydrocarbon charging from the Carboniferous source rocks. The Glauconitic play is defined to include the oil pools in the Glauconitic sandstone. These sandstone units were deposited as valley fill deposits over most of Central Alberta during minor fluctuations in sea level. The northwestern limit consists of barrier beach deposits in the Hoadley trend which runs in a northeast-southwest direction, perpendicular to the trend of the river valleys. During lower sea level intervals, rivers incised into the underlying Ostracod sediments and these incised valleys were then back-filled during intervals of higher sea level. Each sea level fluctuation cycle resulted in more valley fill deposits.

The Board's assessment is based on a discovered oil-in-place estimate of 78.2 million m^3, contained in 52 designated pools (Table 6.9). This was supplemented by the addition of

TABLE 6.9

Glauconitic – Heavy, Central Alberta

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
52	78,158	11,101	8,029	3,072	1033	37,492	3,593	1,085	115,649	14,694	6,665

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Alberta	11,101		Ave	Min	Max	Ave	Min	Max	1951
			1017	786	1496	4	0.5	23	
Porosity (fraction)			**Area (ha)**			**Oil Saturation (fraction)**			**% Undiscovered**
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	32
0.22	0.14	0.29	196	16	4764	0.63	0.39	0.9	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	MEDICINE HAT	GLAUCONITIC C	19790000	30920.0	1	6	2148	2148	6
2	CESSFORD	MANNVILLE C	19510818	29100.0	2	9	1119	3267	9
3	MEDICINE HAT	GLAUCONITIC H	19960213	3089.0	3	12	643	3910	10
4	JOHNSON	GLAUCONITIC B	19810616	2779.0	4	15	447	4357	12
5	MEDICINE HAT	GLAUCONITIC G	19951126	2350.0	5	17	403	4760	13
7	JOHNSON	GLAUCONITIC H	19920725	1460.0	6	19	330	5090	14
8	BANTRY	MANNVILLE M	19650000	1120.0	7	20	281	5371	14
10	ATLEE-BUFFALO	GLAUCONITIC H	19940821	958.0	8	22	247	5618	15
11	JOHNSON	GLAUCONITIC C	19821212	943.0	9	24	224	5842	16
13	CESSFORD	MANNVILLE Z3Z	19910916	628.0	10	25	207	6049	16
14	BANTRY	MANNVILLE PP	19831218	456.0	11	28	195	6244	17
16	ATLEE-BUFFALO	GLAUCONITIC G	19901119	433.0	12	30	190	6434	17
18	JOHNSON	GLAUCONITIC I	19920828	340.0	13	31	182	6616	18
21	JOHNSON	GLAUCONITIC J	19930901	266.0	14	33	178	6794	18
23	BANTRY	MANNVILLE XX	19901213	240.0	15	35	171	6965	19
26	RUMSEY	GLAUCONITIC F	19841030	204.0	16	37	166	7131	19
27	SUFFIELD (poil)			200.5	17	38	163	7294	19
29	CESSFORD	MANNVILLE A4A	19910821	195.0	18	39	161	7455	20
32	JOHNSON	GLAUCONITIC E	19830816	180.0	19	40	155	7610	20
34	BANTRY	MANNVILLE O	19640702	173.0	20	41	153	7763	21
36	SUFFIELD (poil)			170.4	21	45	150	7913	21
42	CESSFORD	MANNVILLE G3G	19890808	152.0	22	47	147	8060	21
43	ATLEE-BUFFALO	GLAUCONITIC D	19861224	151.0	23	49	145	8205	22
44	CESSFORD	MANNVILLE E4E	19910927	150.0	24	51	142	8347	22
46	CESSFORD	MANNVILLE P2P	19851015	149.0	25	53	141	8488	23
48	JENNER (poil)			146.8	26	54	137	8625	23
50	SUFFIELD (poil)			143.3	27	55	133	8758	23
52	ATLEE-BUFFALO	GLAUCONITIC A	19811027	142.0	28	56	131	8889	24
57	PRINCESS	GLAUCONITIC A	19910729	128.0	29	58	127	9016	24
59	JENNER (poil)			126.4	30	60	122	9138	24
64	CESSFORD	MANNVILLE B4B	19910811	113.0	31	61	120	9258	25
68	COUNTESS (poil)			105.7	32	62	118	9376	25
74	CESSFORD	MANNVILLE T4T	19920717	95.8	33	63	113	9489	25
76	ATLEE_BUFFALO (poil)			94.4	34	65	111	9600	26
77	BERRY (poil)			94.2	35	66	107	9707	26
79	COUNTESS (poil)			93.7	36	67	106	9813	26
84	SUFFIELD (poil)			90.7	37	69	103	9916	26
86	JENNER (poil)			90.1	38	70	101	10017	27
86	JENNER (poil)			90.1	39	71	99	10116	27
					40	72	98	10214	27

157 identified potential pools, containing 5.8 million m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model (Table 6.10). There were no identified miscellaneous pools for this play. The model projects an additional 876 undiscovered pools exist. They are expected to contain 31.6 million m^3 of oil in place. The projected pools include 38 pools that are expected to contain more than 100 thousand m^3 of oil in place each: these capture about one-quarter of the total undiscovered potential. The total resource estimate is 115.6 million m^3, of which 32 percent was undiscovered at year-end 1998.

The largest undiscovered pool is expected to be the sixth ranked pool in this play at 2.1 million m^3, much smaller than the Medicine Hat Glauconitic C pool at 30.9 million m^3 (Figure 6.10). The cross plot information suggests that the largest undiscovered pool would occupy about 200 ha with about seven metres of average net pay (Figure 6.11). The Board's analysis indicates that this is a mature play that has only limited potential for further growth on the heavy oil side.

For the Glauconitic play, approximately 55 percent of the wells have produced less than five thousand m^3 each, accounting for less than three percent of the total production. However, approximately one-third of the wells have produced over 50 thousand m^3 each, accounting for two-thirds of the total production. These highly productive wells have an important role in lowering the average supply costs to the range of \$42-\$46/m^3.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 93.6 to 199.8 million m^3 due to new discoveries, growth in existing pools and the reassignment of some pools to their proper play designation after splitting of the commingled pools. There were 45 new pools found between year-end 1994 and year-end 1998.

6.5 Lloydminster Region

6.5.1 Dina Play

This play includes all the oil pools in the Dina Member of the Lower Mannville Group (Figure 6.1). The Dina Member fills large valleys eroded into the Paleozoic surface, and is believed to be fluvial sourced. This is due in part to its relationship to the McMurray Formation further north. Sand deposits can exceed 90 metres in local areas. Traps are formed by structural drape resulting from salt solution tectonics or by lateral pinchout of the porous sands to tight mudstone. Two-thirds of the oil in the discovered pools is heavy oil.

The Board's assessment is based on a discovered oil-in-place estimate of 230.4 million m^3, contained in 219 pools which consisted of 183 designated pools with an oil in place of 217.2 million m^3, and 36 assigned miscellaneous pools with an oil in place of 13.2 million m^3 in the Saskatchewan portion of the play, about six percent of the volume in designated pools (Table 6.11). This was supplemented by the addition of 247 identified potential pools in the Alberta portion of the play, containing 6.0 million m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model. The model projects an additional 910 undiscovered pools exist. They are expected to contain 39.5 million m^3 of oil in place (Table 6.12). The projected pools include 70 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture 46 percent of the total undiscovered potential. The total resource estimate is 276.1 million m^3, of which 17 percent was undiscovered at year-end 1997/98.

The largest undiscovered pool in this play is expected to be the 12th ranked pool containing 5.3 million m^3 of oil in place, much smaller than the Hayter Dina B pool in Alberta which contains almost 45 million m^3 (Figure 6.12). The cross plot information suggests that the largest

TABLE 6.10

Glauconitic Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^3m^3)	Number of Pools	OIP (10^3m^3)
10 - 100 million	2	60020	0	0
1 - 10 million	5	10798	2	3267
100 - 1000 thousand	25	6894	36	6751
10 - 100 thousand	154	6131	628	20167
<10 thousand	23	163	210	1458
Total	**209**	**84006**	**876**	**31644**

FIGURE 6.10

Pool Rank Plot – Glauconitic

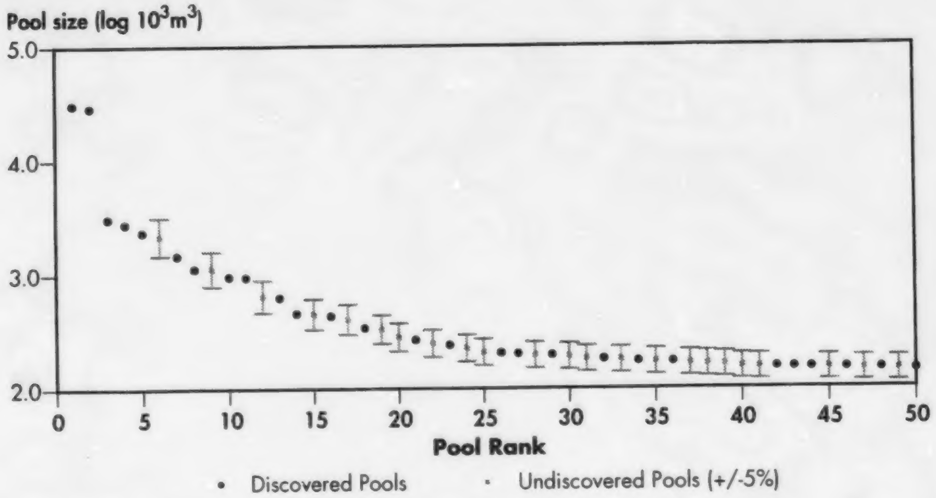


FIGURE 6.11

Cross Plot – Glauconitic

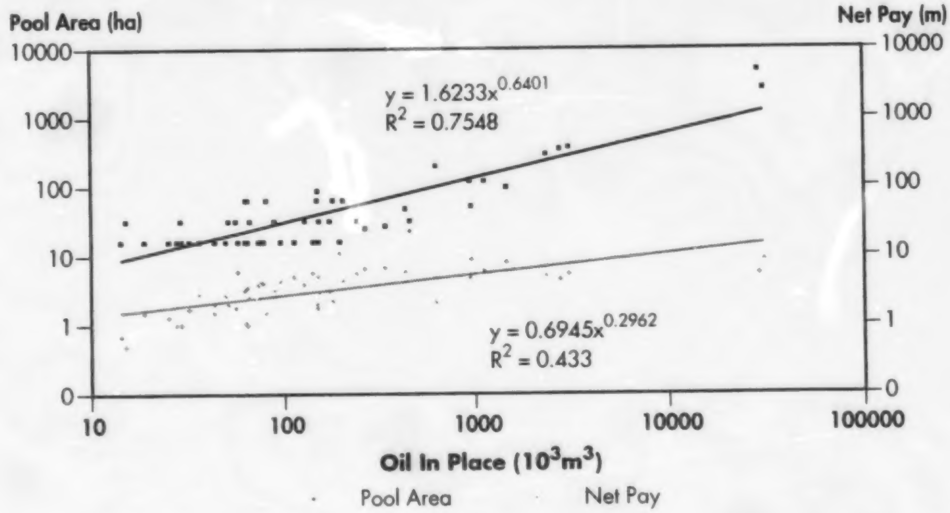


TABLE 6.11

Dina – Heavy, Lloydminster Region, Alberta and Saskatchewan

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
219	230,387	39,707	25,442	14,265	1157	45,663	3,513	1,376	276,050	43,220	17,778

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr
Alberta	25,610		Ave	Min	Max	Ave	Min	Max	1964
Saskatchewan	14,098		899	595	1081	4.1	1.1	13	
Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	17
0.25	0.13	0.34	91	4	1776	0.68	0.39	0.9	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	HAYTER	DINA B	19690916	44910.0	1	12	5283	5283	12
2	MANTARIO N. (SK)	BASAL MANNVILLE	19941125	18279.0	2	28	1029	6312	14
3	CACTUS LAKE (SK)	BASAL MANNVILLE	19741129	17931.0	3	35	787	7099	16
4	SENLAC (SK)	DINA SAND	19680927	15209.0	4	36	759	7858	17
5	HAYTER	DINA A TOTAL	19540122	12280.0	5	42	667	8525	19
6	MARENGO S. (SK)	BASAL MANNVILLE	19910813	11225.5	6	45	596	9121	20
7	PROVOST	BASAL QUARTZ C	19750406	9852.0	7	48	509	9630	21
8	PROVOST	DINA N	19570823	7693.0	8	53	461	10091	22
9	HAYTER	DINA Q	19780000	6930.0	9	54	456	10547	23
10	EYEHILL (SK)	DINA SAND	19711128	6025.0	10	58	394	10941	24
11	MANTARIO E. (SK)	BASAL MANNVILLE	19950630	5541.0	11	61	369	11310	25
13	N. HOOSIER (SK)	BASAL MANNVILLE SD	19641009	5281.0	12	65	353	11663	26
14	PROVOST	DINA O	19561117	5265.0	13	67	311	11974	26
15	Misc. # 1	DINA		5101.6	14	68	302	12276	27
16	HAYTER	DINA I	19840710	4727.0	15	69	300	12576	28
17	PROVOST	DINA A	19820000	3498.0	16	73	271	12847	28
18	ONWARD (SK)	BASAL MANNVILLE SD	19870709	2877.7	17	77	253	13100	29
19	PROVOST	DINA YY	19880625	2654.0	18	83	239	13339	29
20	RUTLAND (SK)	DINA SAND	19930906	2290.0	19	84	238	13577	30
21	PROVOST	DINA L	19841112	1961.0	20	85	235	13812	30
22	PROVOST	DINA Q	19840710	1866.0	21	89	220	14032	31
23	Misc. # 2	DINA		1673.7	22	93	209	14241	31
24	PROVOST	DINA O2O	19760524	1299.0	23	94	206	14447	32
25	PROVOST	ELLERSLIE PP	19840903	1141.0	24	95	202	14649	32
26	Misc. # 3	DINA		1096.8	25	96	197	14846	33
27	PROVOST	ELLERSLIE D	19820716	1062.0	26	99	190	15036	33
29	HAYTER	DINA H	19791212	1007.0	27	103	183	15219	33
30	PROVOST	DINA R	19831123	962.0	28	104	181	15400	34
31	PROVOST	DINA B2B	19810509	850.0	29	107	181	15581	34
32	HAYTER	DINA D	19730824	838.0	30	109	175	15756	35
33	Misc. # 4	DINA		812.4	31	112	169	15925	35
34	PROVOST	DINA Q3Q	19880804	790.0	32	114	168	16093	35
37	PROVOST	DINA F3F	19900220	755.0	33	116	164	16257	36
38	SEDGEWICK	BASAL MANNVILLE C	19840701	729.0	34	117	163	16420	36
39	CHAUVIN SOUTH	DINA C	19880617	715.0	35	118	162	16582	36
40	PROVOST	DINA PP	19880811	702.0	36	121	158	16740	37
41	PROVOST	ELLERSLIE T	19840322	673.0	37	126	154	16894	37
43	PROVOST	DINA H7H	19960918	664.0	38	128	152	17046	37
44	Misc. # 5	DINA		638.5	39	130	150	17196	38
46	PROVOST	DINA RR	19880617	542.0	40	131	150	17346	38

undiscovered pool would occupy 400 ha with an average net pay of six metres (Figure 6.13). Industry input was fairly extensive and provided a wide range of opinions such as: the undiscovered resource was too low; the undiscovered resource was correct; the largest undiscovered pool was too small; the play should be combined with the Cummings play; the minimum pool size should be 350 thousand m^3; and the minimum pool size should be 1.6 million m^3. This variance of opinion may stem from some pool designation or pool naming problems for this region, where some overlap of the Cummings and Dina pools exist. Discussions with the GSC staff indicated that its experience showed that a smaller resource potential would be generated if the two plays were combined. The Board decided to leave the play results as indicated.

TABLE 6.12

Dina Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^3m^3)	Number of Pools	OIP (10^3m^3)
10 - 100 million	6	119835	0	0
1 - 10 million	21	78842	2	6312
100 - 1000 thousand	98	27422	68	14668
10 - 100 thousand	284	10081	572	16888
<10 thousand	59	403	268	1601
Total	**466**	**236398**	**910**	**39469**

FIGURE 6.12

Pool Rank Plot – Dina

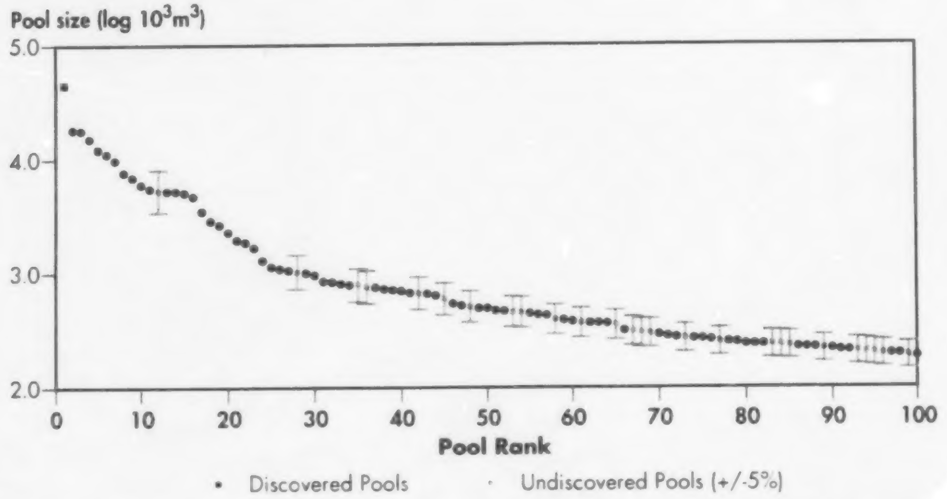
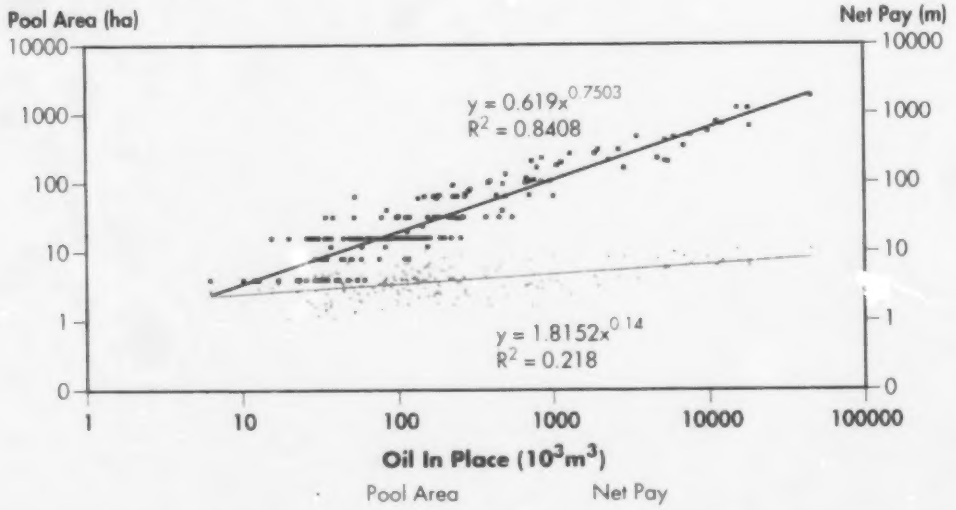


FIGURE 6.13

Cross Plot – Dina



For the Dina play, approximately 50 percent of the wells have produced less than five thousand m^3 each, while 75 percent of the wells produced less than 10 thousand m^3 each. Those wells capture about 35 percent of the total production. An additional 40 percent of the total production comes from wells that have produced between 10 and 20 thousand m^3. The average supply costs are estimated to be in the range of \$79-\$91/m^3.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 148.8 to 338.2 million m^3 due to new discoveries, growth in existing pools, the inclusion of miscellaneous volumes and the reassignment of some pools to their proper play designation after splitting of the commingled pools. There were 49 new pools found between year-end 1994 and year-end 1997/98.

6.5.2 Cummings Play

This play includes all oil pools in the Cummings Member of the Lower Mannville Group (Figure 6.1). The Cummings Member represents the uppermost part of the transgressive phase of Mannville deposition. The sediments consist of shoreface sandstones with associated nonmarine, marginal marine and incised valley deposits. Traps result from both stratigraphic and salt solution tectonic means. Ninety-five percent of the pools contain heavy oil.

The Board's assessment is based on a discovered oil-in-place estimate of 212.2 million m^3, contained in 157 pools which consisted of 118 designated pools with an oil in place of 187.3 million m^3, and 39 assigned miscellaneous pools with an oil in place of 24.9 million m^3 in the Saskatchewan portion of the play, about 12 percent of the volume in designated pools (Table 6.13). This was supplemented by the addition of 287 identified potential pools in the Alberta portion of the play, containing 6.8 million m^3 of oil in place, in order to better define the play's distribution in the geo-anchored model. The model projects an additional 1,695 undiscovered pools exist. They are expected to contain 53.3 million m^3 of oil in place (Table 6.14). The projected pools include 83 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture about 40 percent of the total undiscovered potential. The total resource estimate is 272.3 million m^3, of which 22 percent was undiscovered at year-end 1997/98.

The largest undiscovered pool should be the 10th ranked pool in this play containing about 4.6 million m^3, much smaller than the Winter Cummings pool (commingled with the Dina) in Saskatchewan which contains 69.6 million m^3 (Figure 6.14). The cross plot information suggests that the largest undiscovered pool would occupy 300 ha with an average net pay of eight metres (Figure 6.15).

Approximately 70 percent of the wells in the Cummings play have produced less than five thousand m^3 each while 80 percent have produced less than 10 thousand m^3 each. One-half of the total production comes from these wells. The remainder of the total production was captured by wells that have produced between 10 and 22 thousand m^3 each. As a result, the cost structure is similar to that of Ostracod play. The average supply costs are relatively high, estimated to be in the range of \$91-\$106/m^3.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 50.6 to 193.8 million m^3 due to new discoveries, expansion of existing pools, the inclusion of miscellaneous volumes, and the reassignment of some pools to their proper play designation after splitting of the commingled pools. There were 32 new pools found between year-end 1994 and year-end 1997/98.

TABLE 6.13

Cummings – Heavy, Lloydminster Region, Alberta and Saskatchewan

Discovered Pools					Undiscovered Pools			Total Resources			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
157	212,158	16,848	9,673	7,175	1982	60,153	6,377	2,139	272,311	23,225	13,552

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr.
Alberta	8,910		Ave	Min	Max	Ave	Min	Max	1968
Saskatchewan	7,938		798	610	1041	3.6	0.5	16	
Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	22
0.27	0.2	0.34	123	4	3000	0.72	0.39	0.91	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	WINTER (SK)	CUMMINGS SAND	19810610	69568.5	1	10	4617	4617	8
2	SODA LAKE (SK)	CUMMINGS SAND	19780305	31927.5	2	16	1684	6301	10
3	SENLAC (SK)	CUMMINGS SAND	19680927	15209.0	3	23	1069	7370	12
4	WINTER SOUTH (SK)	CUMMINGS SAND	19800914	13939.2	4	25	852	8222	14
5	PROVOST	CUMMINGS I	19840201	12980.0	5	28	699	8921	15
6	Misc. # 1	Cummings		9269.6	6	32	591	9512	16
7	RIVERCOURSE	CUMMINGS A	19771015	7066.0	7	35	508	10020	17
8	EYEHILL NORTH (SK)	CUMMINGS SAND	19851005	6573.0	8	36	466	10486	17
9	EYEHILL (SK)	CUMMINGS SAND	19710622	6026.0	9	40	409	10895	18
11	Misc. # 2	Cummings		3085.9	10	41	378	11273	19
12	PROVOST	CUMMINGS S	19861215	2572.0	11	43	340	11613	19
13	RUTLAND (SK)	CUMMINGS SAND	19930831	2290.0	12	44	329	11942	20
14	Misc. # 3	Cummings		2036.3	13	47	311	12253	20
15	PROVOST	CUMMINGS A4A	19970802	1954.0	14	50	287	12540	21
17	LLOYDMINSTER	CUMMINGS A	19770722	1639.0	15	52	280	12820	21
18	PROVOST	UPR MANNVILLE M6M	19910000	1520.0	16	54	269	13089	22
19	Misc. # 4	Cummings		1516.9	17	56	260	13349	22
20	PROVOST	CUMMINGS VVV	19920715	1299.0	18	57	252	13601	23
21	Misc. # 5	Cummings		1198.6	19	58	244	13845	23
22	PROVOST	CUMMINGS B2B	19851128	1096.0	20	60	238	14083	23
24	Misc. # 6	Cummings		981.2	21	64	233	14316	24
26	Misc. # 7	Cummings		822.4	22	65	230	14546	24
27	Misc. # 8	Cummings		701.2	23	66	225	14771	25
29	PROVOST	CUMMINGS A2A	19901017	646.0	24	71	217	14988	25
30	PROVOST	CUMMINGS N	19840000	626.0	25	72	213	15201	25
31	Misc. # 9	Cummings		605.4	26	73	211	15412	26
33	Misc. # 10	Cummings		527.8	27	76	206	15618	26
34	PROVOST	CUMMINGS NNN	19890710	510.0	28	77	201	15819	26
37	Misc. # 11	Cummings		463.7	29	79	196	16015	27
38	HAYTER	CUMMINGS A	19811202	416.0	30	80	192	16207	27
39	Misc. # 12	Cummings		409.8	31	81	190	16397	27
42	Misc. # 13	Cummings		364.0	32	83	185	16582	28
45	ALTARIO	CUMMINGS A	19890922	327.0	33	85	180	16762	28
46	Misc. # 14	Cummings		324.6	34	86	178	16940	28
48	HAYTER	CUMMINGS B	19810904	295.0	35	89	174	17114	28
49	Misc. # 15	Cummings		290.3	36	91	171	17285	29
51	PROVOST	CUMMINGS W2W	19940626	286.0	37	93	170	17455	29
53	HAYTER	CUMMINGS I	19950818	271.0	38	97	167	17622	29
55	Misc. # 16	Cummings		260.3	39	98	166	17788	30
59	PROVOST	CUMMINGS C	19820314	243.0	40	100	162	17950	30

6.5.3 Colony to Lloydminster Play

This play includes oil pools in the Colony, McLaren, Waseca, Rex, General Petroleum, Sparky and Lloydminster Members of the Upper Mannville Group (Figure 6.1). This stratigraphic interval consists of at least seven transgressive-regressive shoreline successions deposited during oscillations of sea level during the time of deposition. Regional shoreline deposits are interrupted by valley fill deposits which may be structurally controlled by salt solution tectonics. During low sea level, there was extensive downcutting of the river valleys which became sediment filled during subsequent high sea level intervals. Valley fill deposits consist of mudstone (local seals) or sandstone (local reservoirs). Other trapping mechanisms include structural drape over highs on

TABLE 6.14

Cummings Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^3m^3)	Number of Pools	OIP (10^3m^3)
10 - 100 million	5	143624	0	0
1 - 10 million	15	49142	3	7370
100 - 1000 thousand	67	16679	80	15938
10 - 100 thousand	265	8924	949	25876
<10 thousand	92	600	663	4157
Total	**444**	**218970**	**1695**	**53341**

FIGURE 6.14

Pool Rank Plot – Cummings

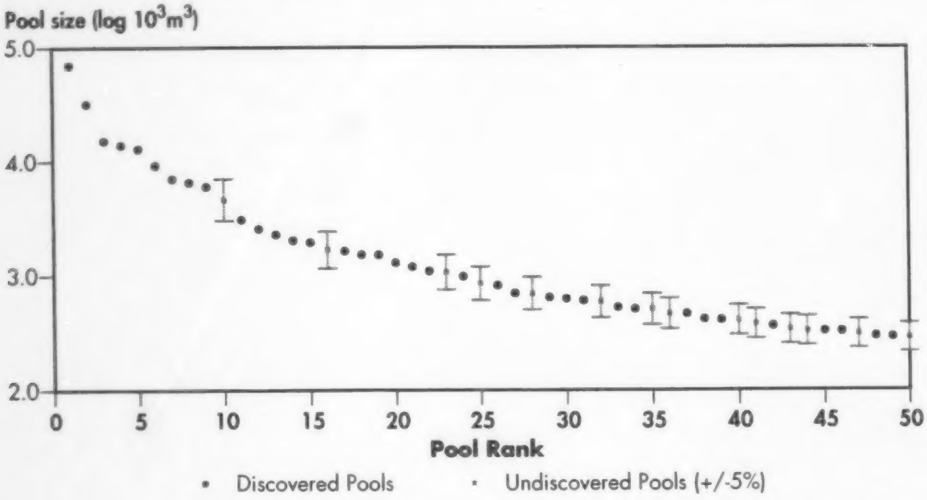
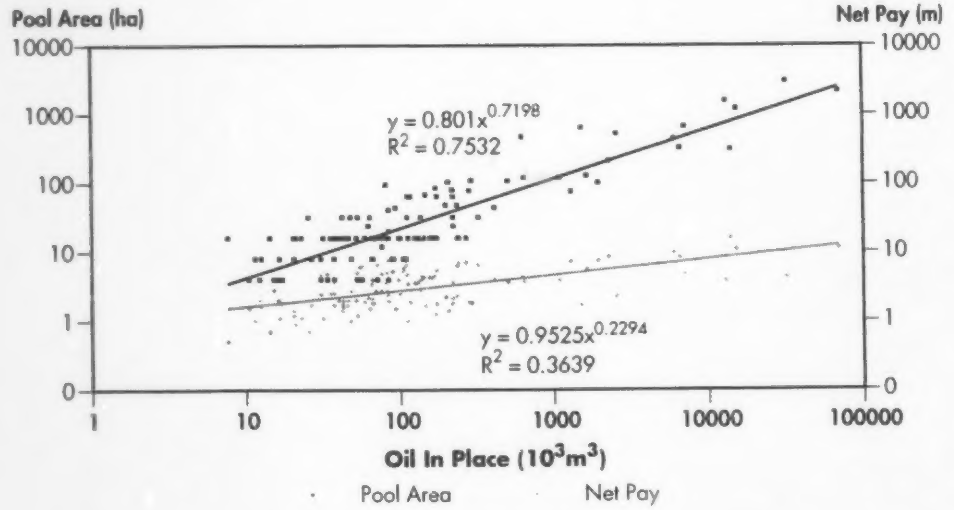


FIGURE 6.15

Cross Plot – Cummings



the pre-Mannville unconformity, over deeper sand deposits or as a result of salt tectonics. The seven Members were combined for this assessment, recognizing that the undiscovered potential generated may be conservative.

The Board's assessment is based on a discovered oil-in-place estimate of 2 473.8 million m^3, contained in 1320 pools which consisted of 676 designated pools with an oil in place of 2 198 million m^3, and 644 assigned miscellaneous pools with an oil in place of 218.8 million m^3, about 10 percent of the volume in designated pools (Table 6.15). This was supplemented by the addition of 1,440 identified potential pools, containing 56.6 million m^3 of oil in place in the Alberta portion of the play, in order to better define the play's distribution in the geo-anchored model. The model

TABLE 6.15

Colony to Lloydminister – Heavy, Lloydminster Region, Alberta and Saskatchewan

Discovered Pools					**Undiscovered Pools**			**Total Resources**			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
1,320	2,417,184	220,470	150,174	70,296	21,790	1,236,221	83,151	23,110	3,653,405	303,621	153,447

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)		Depth from KB (metres)			Net Pay (metres)			Discovery Yr
		Ave	Min	Max	Ave	Min	Max	
Alberta	91,157							1947
Saskatchewan	129,314	657	359	1045	3.9	0.6	21.6	

Porosity (fraction)			Area (ha)			Oil Saturation (fraction)			% Undiscovered
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	33
0.28	0.17	0.36	330	4	7634	0.72	0.25	0.91	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	CELTIC	WASECA SAND	19681030	109945.6	1	41	15923	15923	1
2	ABERFELDY	SPARKY SAND	19570702	93436.0	2	52	12563	28486	2
3	EPPING	SPARKY SAND	19511024	76819.0	3	69	10607	39093	3
4	LLOYDMINSTER	SPARKY	19430000	60253.0	4	73	9709	48802	4
5	TANGLEFLAGS	G.P. SAND	19710328	56768.0	5	76	8828	57630	5
6	TANGLEFLAGS	LLOYDMINSTER SD	19651110	55784.0	6	77	8798	66428	6
7	CHAUVIN SOUTH	MANNVILLE MU #1	19520000	50220.0	7	92	6712	73140	6
8	CACTUS LAKE N.	MCLAREN SAND	19790927	47143.0	8	94	6396	79536	7
9	MORGAN	LLOYD A	19620000	42895.0	9	99	6143	85679	7
10	CELTIC	SPARKY SAND	19690512	41913.9	10	104	5704	91383	8
11	TANGLEFLAGS N.	LLOYD/CUMMINGS SD	19770616	41021.8	11	110	5498	96881	8
12	WILDMERE	LLOYDMINSTER A	19630000	38210.0	12	112	5281	102162	9
13	WAINWRIGHT	WAINWRIGHT	19230000	37212.0	13	116	4754	106916	9
14	MORGAN	REX A	19620000	33570.0	14	125	4312	111228	9
15	GOLDEN LAKE S.	SPARKY SAND	19641020	32283.0	15	134	3925	115153	10
16	GOLDEN LAKE S.	WASECA SAND	19641020	30604.0	16	135	3764	118917	10
17	GULLY LAKE	WASECA SAND	19490318	27876.0	17	139	3539	122456	10
18	LASHBURN	WASECA SAND	19600000	27543.0	18	143	3322	125778	11
19	EDAM	WASECA SAND	19720000	27495.2	19	145	3238	129016	11
20	TANGLEFLAGS	SPARKY SAND	19690818	27000.0	20	146	3212	132228	11
21	CELTIC	G.P. SAND	19680000	25708.9	21	151	3018	135246	11
22	LLOYDMINSTER	SPARKY K	19470000	24460.0	22	152	2996	138242	12
23	MARSDEN SOUTH	SPARKY SAND	19790224	23609.0	23	156	2842	141084	12
24	PROVOST	UPR MANNVILLE BB	19771010	22270.0	24	158	2810	143894	12
25	PROVOST	UPR MANNVILLE U8U	19730608	22160.0	25	161	2630	146524	12
26	PROVOST	UPR MANNVILLE B	19520000	21220.0	26	162	2600	149124	13
27	VIKING-KINSELLA	WAINWRIGHT B	19740305	20910.0	27	170	2435	151559	13
28	EDAM WEST	SPARKY/G.P. SAND	19820303	20627.0	28	182	2147	153706	13
29	SILVERDALE	SPARKY SAND	19680000	20543.7	29	183	2147	155853	13
30	GOLDEN LAKE N.	SPARKY SAND	19641112	20422.0	30	185	2127	157980	13
31	GOLDEN LAKE N.	WASECA SAND	19640701	19987.0	31	187	2102	160082	14
32	PROVOST	UPR MANNVILLE T8T	19830000	19720.0	32	198	1933	162015	14
33	LLOYDMINSTER	SPARKY G	19630000	19500.0	33	202	1903	163918	14
34	PLOVER LAKE	MCLAREN SAND	19850217	19122.0	34	203	1896	165814	14
35	EPPING	G.P. SAND	19520822	18939.0	35	209	1795	167609	14
36	NORTHMINSTER	SPARKY SAND	19590528	18389.0	36	211	1751	169360	14
37	EDAM WEST	WASECA SAND	19821108	17760.8	37	214	1726	171086	15
38	STANDARD HILL	WASECA SAND	19630000	17124.7	38	215	1698	172784	15
39	MORGAN	SPARKY A	19620000	16785.0	39	216	1677	174461	15
40	DEE VALLEY	WASECA SAND	19670704	16597.2	40	217	1672	176133	15

projects an additional 20,340 undiscovered pools exist. They are expected to contain 1 179.6 million m^3 of oil in place (Table 6.16). The projected pools include 2,054 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture 56 percent of the total undiscovered potential. The total resource estimate is 3 653.2 million m^3, of which 33 percent was undiscovered at year-end 1997/98.

The largest undiscovered pool in this play is expected to be the 41st ranked pool, containing about 15.9 million m^3. This is much smaller than the largest discovered pool, the Celtic Waseca Sand pool in Saskatchewan, which contains 110 million m^3 (Figure 6.16). The cross plot information suggests that the largest undiscovered pool would occupy about 400 ha with an average net pay of seven metres (Figure 6.17). Industry indicated concern that the largest undiscovered pool was too small and that the total resource potential was too low. One company suggested that the minimum pool size should be 400 thousand m^3; this would reduce the developable portion of the undiscovered potential to 303 pools with an undiscovered resource of 360.5 million m^3. The Board acknowledges the conservative nature of its estimate, but has decided to use the model's output until additional data warrants a re-evaluation.

In this multi-horizon play, approximately 70 percent of the wells have produced less than five thousand m^3 each and 80 percent of the wells have produced less than 10 thousand m^3 each. These

TABLE 6.16

Colony to Lloydminister Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^3m^3)	Number of Pools	OIP (10^3m^3)
10 - 100 million	68	1706664	3	39094
1 - 10 million	165	526716	82	193183
100 - 1000 thousand	611	172470	1969	435972
10 - 100 thousand	1748	66746	14730	489986
<10 thousand	179	1188	3555	21386
Total	**2770**	**2473784**	**20340**	**1179621**

FIGURE 6.16

Pool Rank Plot – Colony to Lloydminister

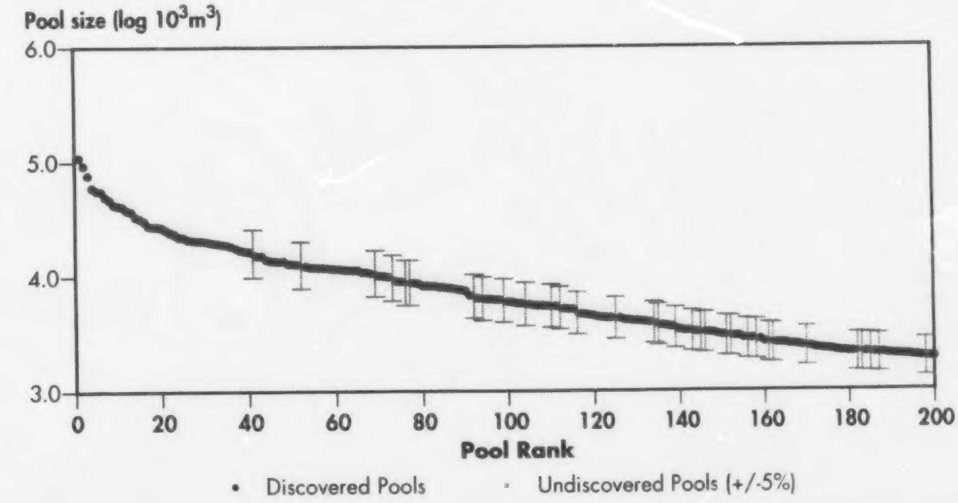
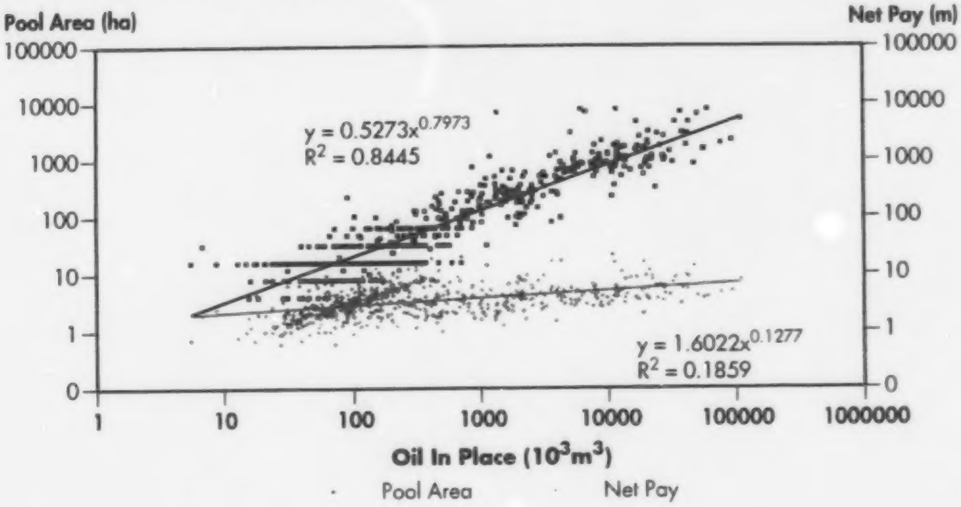


FIGURE 6.17

Cross Plot – Colony to Lloydminister



wells only capture one-third of the total production. The highly productive wells, those that have produced over 30 thousand m^3, capture an additional 15 percent of the total production. The average supply costs are estimated to be in the range of \$79-\$91/m^3. The average costs are lower than that of the Ostracod play due to the larger percentage of wells which produced over 30 thousand m^3 in this play.

Compared with the GSC's 1998 report, the discovered oil in place for light and heavy oils has increased from 1 870.2 to 2 421.9 million m^3 due to new discoveries, growth in existing pools, the inclusion of miscellaneous volumes, and the reassignment of some pools to their proper play designation after splitting of the commingled pools. There were 92 new pools found between year-end 1994 and year-end 1997/98. This growth is a direct result of the extensive oil drilling activity that took place during 1996 and 1997.

6.6 Saskatchewan Region

6.6.1 Cantuar Play

This play includes oil pools in the Mannville section equivalent in Saskatchewan, including the Cantuar, Basal Mannville and Wapella Formations (Figure 6.1). The Cantuar and Basal Mannville pools are found in southwestern Saskatchewan, while the Wapella pool is found in southeastern Saskatchewan. These deposits are found in areas that had a low subsidence rate in the Williston Basin portion of Western Canada. Sedimentation is mainly restricted to non-marine to marginal marine type settings. The deposits consist of numerous valley fill sequences.

The Board's assessment is based on a discovered oil-in-place estimate of 118.4 million m^3 found in 59 discovered pools (Table 6.17). These discovered pools consist of 18 designated pools containing 92.5 million m^3 and 41 assigned miscellaneous pools containing 25.9 million m^3, about 28 percent of the volume found in the designated pools. There are no potential pools for this play. The model projects an additional 3,662 undiscovered pools exist. They are expected to contain 176.2 million m^3 of oil in place (Table 6.18). The projected pools include 363 pools that are expected to contain more than 100 thousand m^3 of oil in place each, these capture about 60 percent of the total undiscovered potential. The total resource estimate is 294.6 million m^3, of which 60 percent was undiscovered at year-end 1997.

The largest undiscovered pool is expected to be the 10th ranked pool in the play, containing 4.1 million m^3. This is much smaller than the largest discovered pool at Cantuar Main, which contains 22.2 million m^3 (Figure 6.18). The cross plot information suggests that the largest undiscovered pool would occupy 300 ha with an average net pay of seven metres (Figure 6.19). One company questioned whether the Wapella pool should be included. As the play is defined, the Board believes that this pool should be included. This suggests that there is a broader area of southern Saskatchewan that could be targeted for new exploration efforts.

TABLE 6.17

Cantuar – Heavy, Saskatchewan

Discovered Pools					**Undiscovered Pools**			**Total Resources**			
Number	OOIP	Recoverable	Cumulative Production	Remaining Reserves	Number	OOIP	Recoverable	Number	OOIP	Recoverable	Remaining Discovered and Undiscovered
	thousand cubic metres					thousand cubic metres			thousand cubic metres		
59	118,410	15,980	10,572	5,408	3661	176,222	15,310	3,720	294,661	31,290	20,718

RESERVOIR PARAMETERS IN DISCOVERED POOLS

Discovered Reserves by Province (10^3m^3)			Depth from KB (metres)			Net Pay (metres)			Discovery Yr
Saskatchewan	15,980		Ave	Min	Max	Ave	Min	Max	1952
			992	701	1100	5.7	1.5	11.7	
Porosity (fraction)			**Area (ha)**			**Oil Saturation (fraction)**			**% Undiscovered**
Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	60
0.25	0.18	0.29	454	16	1591	0.63	0.41	0.7	

Individual Pool Information

Discovered Pools (10^3m^3)					Undiscovered Pools (10^3m^3)				
Rank	Field - Pool Name		Date	OOIP	Number	Rank	OOIP	Cum	Cum %
1	CANTUAR MAIN	CANTUAR SAND	19520723	22218.0	1	10	4056	4056	2
2	WAPELLA	WAPELLA SAND	19521030	17641.7	2	12	3034	7090	4
3	WEBB	CANTUAR SAND	19950207	11561.8	3	14	2098	9188	5
4	Misc. # 1	CANTUAR		9196.9	4	16	1901	11089	6
5	BEVERLEY	CANTUAR SAND	19690808	8340.0	5	17	1620	12709	7
6	GULL LAKE	BASAL CANTUAR SAND	19530606	7850.0	6	20	1431	14140	8
7	BEVERLEY NORTH	CANTUAR SAND	19690808	6257.0	7	21	1352	15492	9
8	CANTUAR EAST	CANTUAR SAND	19560523	5626.0	8	22	1229	16721	9
9	SUFFIELD	BASAL CANTUAR SAND	19961104	5010.2	9	24	1178	17899	10
11	Misc. # 2	CANTUAR		3088.9	10	25	1101	19000	11
13	JAVA NORTH	CANTUAR SAND	19850422	2238.9	11	26	1068	20068	11
15	Misc. # 3	CANTUAR		2046.9	12	28	1039	21107	12
18	Misc. # 4	CANTUAR		1530.0	13	30	992	22099	13
19	BEVERLEY EAST	CANTUAR SAND	19850308	1440.0	14	32	949	23048	13
23	Misc. # 5	CANTUAR		1212.7	15	33	931	23979	14
27	WEBB SOUTH	CANTUAR SAND	19960128	1045.6	16	34	911	24890	14
29	Misc. # 6	CANTUAR		995.7	17	35	894	25784	15
31	JAVA	CANTUAR SAND	19550827	975.1	18	36	879	26663	15
38	Misc. # 7	CANTUAR		837.1	19	37	846	27509	16
39	FOSTERTON SOUTH	CANTUAR SAND	19651127	835.1	20	40	831	28340	16
47	ANTELOPE	CANTUAR SAND	19960604	731.8	21	41	803	29143	17
49	Misc. # 8	CANTUAR		715.7	22	42	789	29932	17
54	SEWARD	BASAL MANNVILLE	19960105	670.6	23	43	777	30709	17
					24	44	766	31475	18
					25	45	743	32218	18
					26	46	733	32951	19
					27	48	723	33674	19
					28	50	703	34377	20
					29	51	692	35069	20
					30	52	682	35751	20
					31	53	672	36423	21
					32	55	653	37076	21
					33	56	643	37719	21
					34	57	633	38352	22
					35	58	624	38976	22
					36	60	604	39580	22
					37	61	594	40174	23
					38	62	584	40758	23
					39	63	575	41333	23
					40	64	564	41897	24

TABLE 6.18

Cantuar Play – Summary Table

	Discovered Pools		Undiscovered Pools	
Pool Size (OIP - m^3)	Number of Pools	OIP (10^{3}m^3)	Number of Pools	OIP (10^{3}m^3)
10 - 100 million	3	51422	0	0
1 - 10 million	13	54883	12	21107
100 - 1000 thousand	27	11390	351	86151
10 - 100 thousand	13	707	1945	60107
<10 thousand	2	13	1353	8881
Total	**59**	**118410**	**3661**	**176246**

FIGURE 6.18

Pool Rank Plot – Cantuar

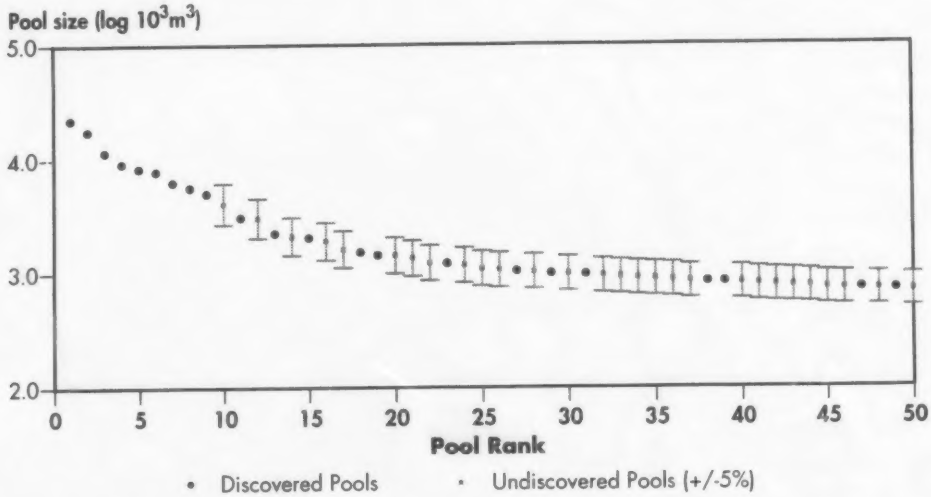
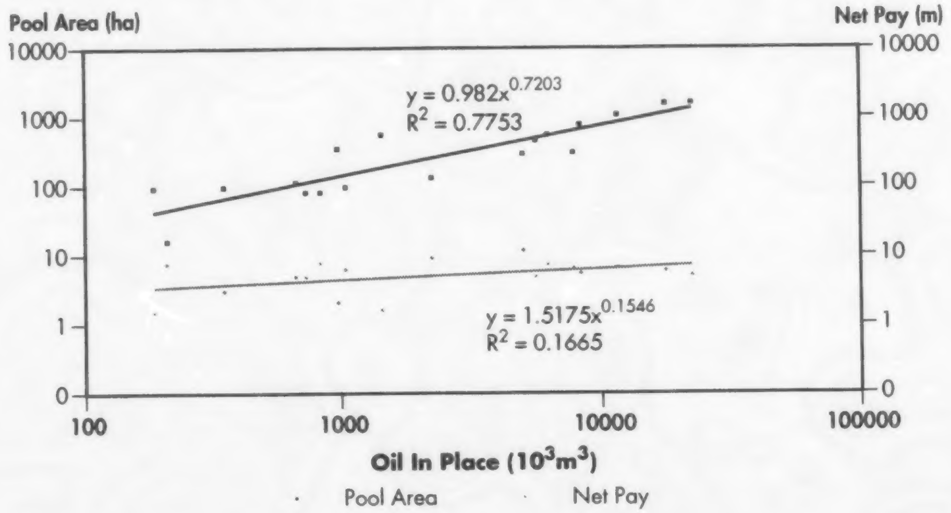


FIGURE 6.19

Cross Plot – Cantuar



Compared with the GSC's 1998 report, the discovered oil in place for heavy oil has increased from 66.1 to 77.1 million m^3 due to new discoveries, growth in existing pools and the inclusion of miscellaneous volumes. There were eight new pools found between year-end 1994 and year-end 1997.

Approximately 60 percent of the wells in the Cantuar play have produced less than five thousand m^3 each, while 70 percent of the wells have produced less than 10 thousand m^3 each. This group of wells only captured 13 percent of the total production. However, about one-quarter of the total production comes from wells which have produced 10 to 20 thousand m^3 and one-half of the total production comes from wells which have produced more than 30 thousand m^3. The average supply costs are estimated to be in the range of $52-$58/ m^3 and are the second lowest of all the Cretaceous conventional heavy oil plays.

6.7 Resource Evaluation Overview

Among the three zones evaluated, the Cretaceous zone has the largest oil in place and largest recoverable volumes. Most of the undiscovered resources are anticipated to come from the four plays with the largest discovered oil-in-place volumes: Colony to Lloydminster, Upper Mannville, Lower Mannville, and Cantuar (Figure 6.20). It is estimated that the discovered oil in place accounts for 65 percent of the total volume in this zone, with two-thirds of the total oil-in-place volume contained in the Colony to Lloydminster play.

Based on the current production practices, the Board estimates that three-quarters of the total recoverable volume has already been discovered and that one-half of the total recoverable volume has been produced (Figure 6.21). Since most new discoveries are expected to come from smaller pools, the recovery from undiscovered pools, as a whole, is expected to be lower than the recovery from the discovered pools. In this zone, the Board estimates that there are 154.6 million m^3 of recoverable oil remaining in the discovered pools and 139.6 million m^3 of recoverable resources still undiscovered. It also estimates that with the application of new technology, improvements to current

FIGURE 6.20

Initial Volume in Place - Cretaceous

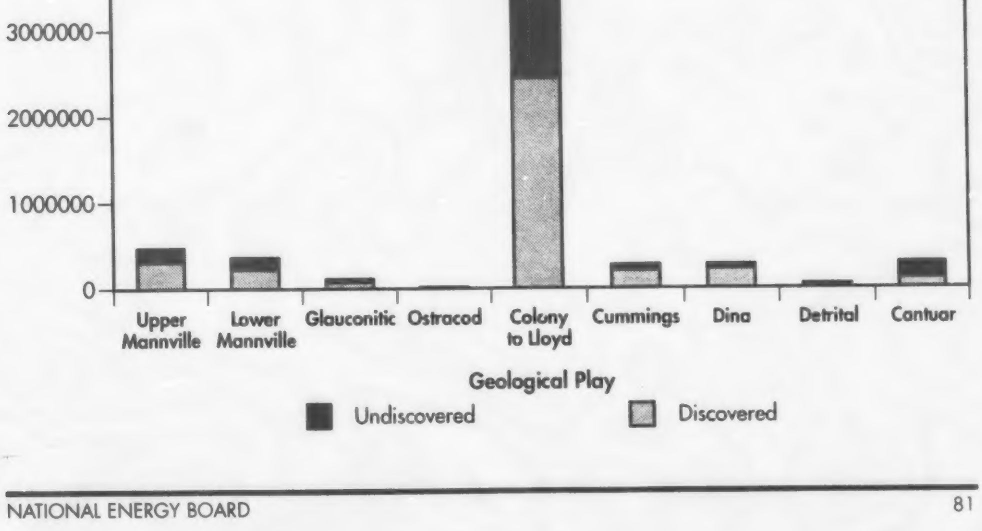
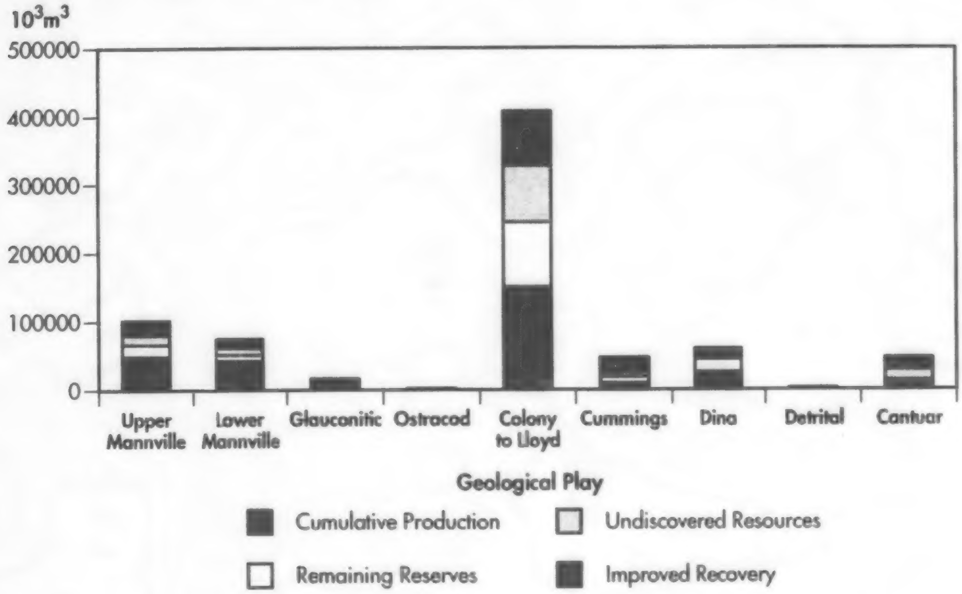


FIGURE 6.21

Recoverable Volumes – Cretaceous



production practices and the initiation of new enhanced recovery schemes, an additional 167.8 million m^3 could be recovered, with the bulk of that coming from the larger-sized discovered pools.

As anticipated, the recovery factors for the larger discovered pools are generally higher than those for the smaller undiscovered pools. The average recovery factor for the discovered pools and undiscovered pools in this zone are 12 and seven percent, respectively. However, with improvements to current production practices, the average recovery factor for this zone could be increased from the current estimate of 11 percent, to 14 percent.

6.7.1 Colony to Lloydminster Play

The oil-in-place and recoverable volumes of this play are, by far, the largest of all the conventional heavy oil plays examined in this study. Only 2,770 (or 12 percent) of the total 23,110 pools in this play have been discovered and 20,212 of the total pools (or 88 percent) are estimated to have an oil-in-place volume of less than 100 thousand m^3 (Figure 6.22).

Almost two-thirds of total oil-in-place volumes are contained in the discovered pools (Figure 6.23). While almost 90 percent of the discovered pools have an oil-in-place volume of less than one million m^3 each, only 67 discovered pools have an oil-in-place volume between 10 million m^3 and 100 million m^3. These pools are important since they contain 1 596.7 million m^3, almost two-thirds of total discovered oil-in-place volume and 29 percent of the estimated total oil in place for this play.

The pool size distribution for undiscovered pools is very different from that for discovered pools. The undiscovered pools are basically divided into two groups: pools with an oil-in-place volume of less than 100 thousand m^3; and pools with an oil-in-place volume between 100 thousand m^3 and one million m^3. About 90 percent of the undiscovered pools and 44 percent of the undiscovered oil in place belong to the first group of pools. The second group of pools is fewer in number but contains about 37 percent of the undiscovered oil in place. There are only four undiscovered pools in the group with oil-in-place volumes between 10 million m^3 and 100 million m^3, this group represents 16 percent of the undiscovered volumes.

The group of pools with oil-in-place volumes between 10 million m^3 and 100 million m^3, contains 70 percent of the discovered reserves. However, over 90 percent of the undiscovered recoverable

FIGURE 6.22

Pool Size Distribution – Colony to Lloydminster

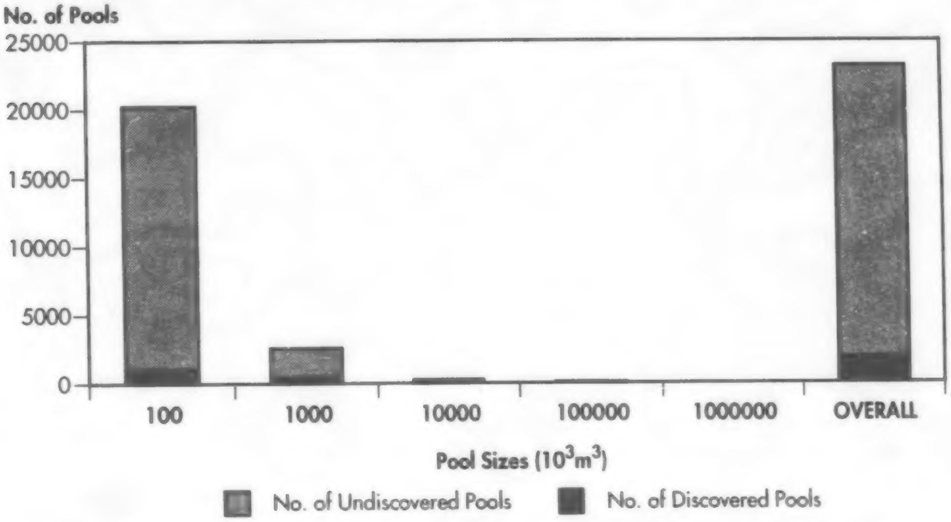
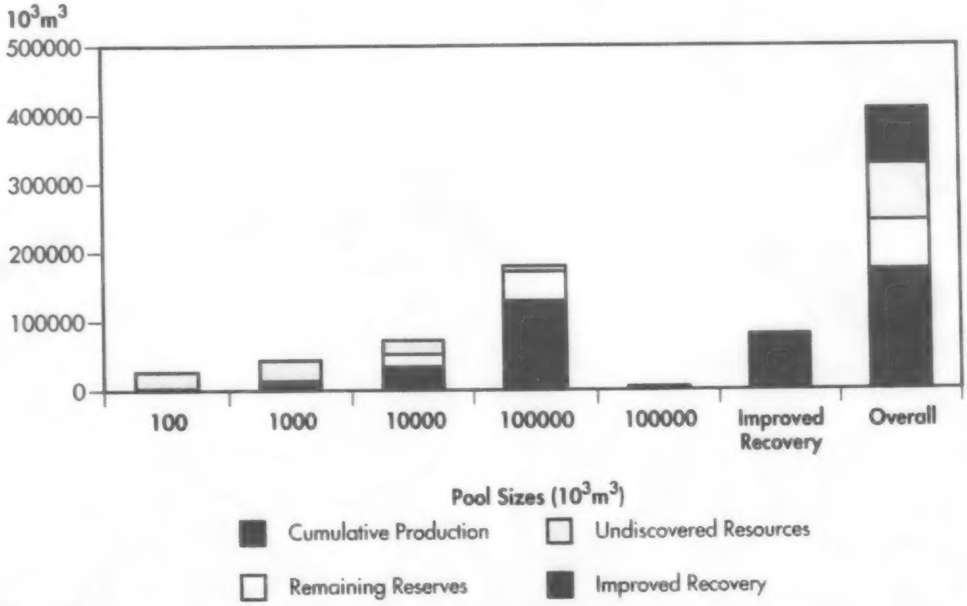


FIGURE 6.23

Recoverables by Source and Pool Size – Colony to Lloydminster



resources are found in pools with oil-in-place volumes of less than 10 million m³. The range of recovery factors for the different groups of pools is shown in Figure 6.24. The overall average recovery factor is approximately 10 percent for discovered pools and seven percent for undiscovered pools and is a function of pool size.

Even though the pools have relatively low recovery factors and have already produced 150 million m³, it is estimated that 94 million m³ of reserves remain to be recovered in the discovered pools. Furthermore, it is expected that 83 million m³ of future production will come from undiscovered pools and that another 79 million m³ of future production could come from enhanced production schemes and improvements to production practices in the discovered pools. The largest discovered pools will continue to play an important role in future development of this play.

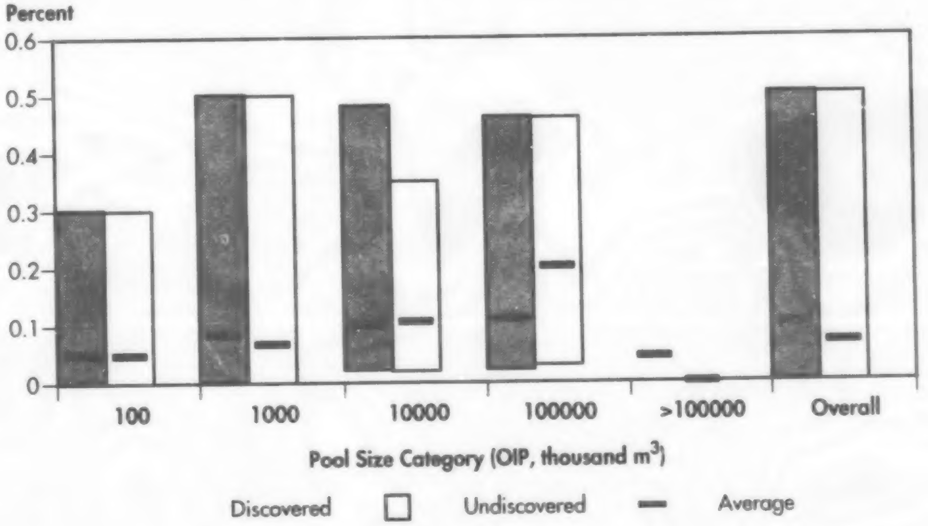
6.8 Summary

The oil-in-place volume of light and heavy oils, for all plays in the Cretaceous zones has increased since the last review by the GSC, from 5 407.8 to 7 020.3 million m³, a growth of 30 percent. Heavy oil represents about three-quarters of the NEB's total oil-in-place volume. While there have been a large number of new discoveries made, there were also some significant reassignments of resources between the different plays. For example, as a result of the splitting of commingled pools and differences in the designation of medium and heavy oils, volumes were added to one play and taken from another. A portion of the growth is also due to the inclusion of the miscellaneous volumes and to the substantial expansion of existing pools. There were a total of 485 new pools discovered between year-end 1994 and year-end 1997/98.

Approximately one-third of the oil-in-place volume is still to be discovered (Table 6.19). Of the nine plays, the Colony to Lloydminster is the most significant because of its size. Its oil-in-place volume is approximately two-thirds of combined oil-in-place volume for the Cretaceous zone and almost 45 percent of all conventional heavy oil in place. The Board estimates that approximately

FIGURE 6.24

Recovery Factors - Colony to Lloydminster



12 percent of the discovered oil in place and eight percent of the undiscovered oil in place will be recovered. Both remaining reserves and undiscovered resources will contribute almost equal volumes to future production. The Board also estimates that the additional resources that could be gained through pool optimization and initiation of additional enhanced recovery projects are important as a source of future production.

The Board's analysis of the heavy oil pools indicates that there is a significant amount of heavy oil left to be found in the Cretaceous plays in the provinces of Alberta and Saskatchewan. For the most part, the undiscovered pools will be smaller than the pools already discovered. However, there are a few large pools still projected to be found. These large pools may require a new exploration strategy to locate them. Some may already have been found, but are not recognized. These pools may result from the amalgamation of a number of smaller recognized or miscellaneous pools, after aggressive pool extension drilling.

TABLE 6.19

Resources of Cretaceous Plays ($10^6 m^3$)

Play	Discovered		Undiscovered	
	Oil in Place	Recoverable	Oil In Place	Recoverable
Lower Mannville	232.3	51.1	131.8	10.3
Upper Mannville	313.8	66.6	160.4	13.8
Detrital	3.2	0.2	45.7	2.0
Ostracod	2.9	0.3	14.0	1.6
Glauconitic	78.2	11.1	37.5	3.6
Dina	230.4	39.7	45.7	3.5
Cummings	212.2	16.8	60.2	6.4
Colony to Lloydminster	2417.2	220.5	1236.2	83.2
Cantuar	118.4	16.0	176.2	15.3
Total	**3608.6**	**422.3**	**1907.7**	**139.7**

CHAPTER SEVEN

7. Economic Analysis Results

7.1 Supply Cost Curves

The capital and operating cost data were determined by examining historical costs for conventional heavy oil projects. The supply costs for typical wells, categorized based on recovery amounts over the life of the well, are summarized and quoted as Canadian dollars, constant, year 2000 (Figure 7.1). The supply costs ranged from a high of approximately \$270/m^3 for a well that produces a cumulative total of 2 500 m^3 to a low of \$34/m^3 for a well that produces a cumulative total of 100 thousand m^3. For a well that produces a cumulative total of 10 thousand m^3, the average supply costs are in the range of \$70-80/m^3. The high supply costs for the low productivity wells are the result of a combination of high capital costs and low oil recovery. The supply costs decrease sharply with an increasing amount of recovery, especially in the recovery range of two to 20 thousand m^3. Beyond the 20 thousand m^3 range, supply costs are influenced more by operating costs than by capital expenditures.

7.1.1 *Supply Cost Curve for Remaining Recoverable Conventional Heavy Oil*

Figure 7.2 shows the supply costs for the three zones and overall remaining recoverable conventional heavy oil. It indicates that supply costs ranged from approximately \$34 to \$270/m^3 and approximately 80 percent of the remaining recoverable could be recovered at a supply cost of \$100/m^3 or less. Similarly, 97 percent of Jurassic, 75 percent of Cretaceous and 88 percent of

FIGURE 7.1

Supply Cost Curve for Typical Wells

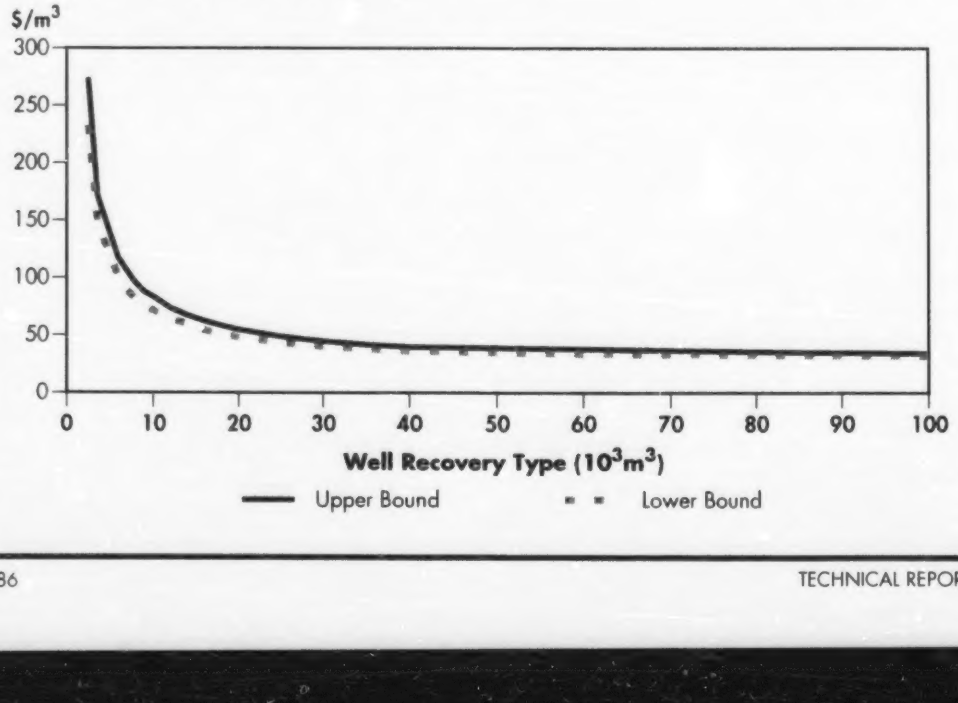
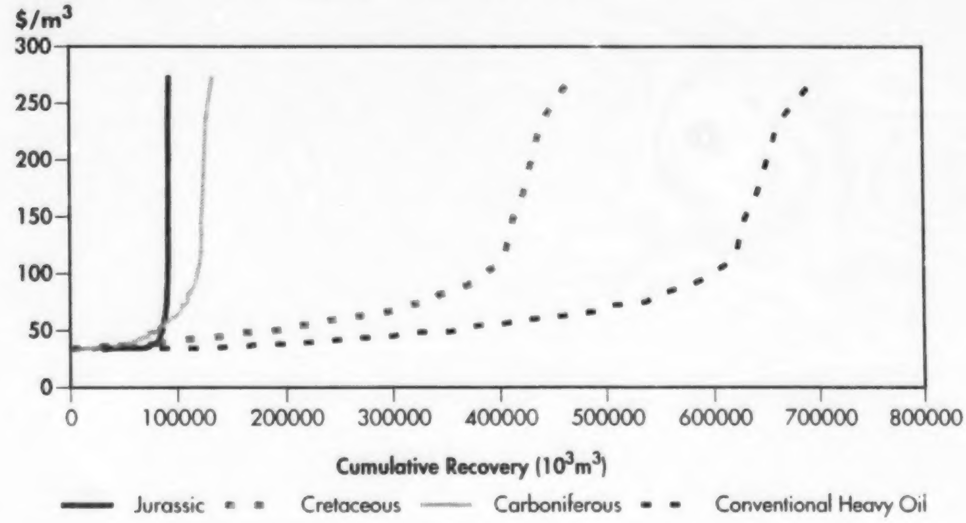


FIGURE 7.2

Supply Cost Curve – Conventional Heavy Oil



Carboniferous recoverable volumes could be recovered at a supply cost of $\$100/\mathrm{m}^3$ or less. The overall mean supply costs are approximately $\$41/\mathrm{m}^3$ for Jurassic, $\$70/\mathrm{m}^3$ for Permian and $\$98/\mathrm{m}^3$ for Cretaceous.

7.1.2 *Supply Cost Curves for Individual Plays*

The mean supply costs for an individual play reflect each play's unique geology, reservoir properties and development plans (Table 7.1).

Based on historical information, over 30 percent of the wells in the Cretaceous Upper Mannville play produced a total of less than one thousand m^3 while approximately one-half of the wells produced a total of less than three thousand m^3 (Figure 7.3). Only two percent of the cumulative production came from wells that produced less than one thousand m^3, and eight percent of the cumulative production was sourced from wells that produced less than three thousand m^3. Therefore, the costs of producing from low productivity wells are offset by the production from high productivity wells in each play. The mean supply costs for each individual play are a reflection of the cumulative frequency distribution for different wells in the same play. The mean supply costs for the Upper Mannville play is about $\$92/\mathrm{m}^3$ (Figure 7.4).

TABLE 7.1

Supply Cost Curve for Zones and Plays

Zone - Play	Supply Costs		
	Low	High	Mean
Carboniferous			70
Rundle Sweetgrass	80	92	91
Mississippian Subcrop	85	98	97
Souris-Tilston	118	138	125
Frobisher-Alida	61	70	68
Middle	47	53	51
Ratcliffe	55	62	61
Bakken	64	73	69
Jurassic			41
Sawtooth	42	46	45
Shaunavon	36	38	38
Roseray-Success	41	44	43
Cretaceous			83
Lower Mannville	81	93	90
Upper Mannville	83	96	92
Detrital	93	108	107
Ostracod	95	111	110
Glauconitic	42	46	44
Dina	79	91	84
Cummings	91	106	102
Colony to Lloydminster	79	91	87
Cantuar	52	58	58

7.2 Summary

The supply cost estimates for each play are based on the analysis of historical production of individual wells and the development of typical well production profiles for that play. The production history indicates that most of the conventional heavy oil wells in Western Canada produce less than 50 thousand m^3 each, over their life. However, the bulk of the production is obtained from a smaller number of more prolific wells which produce more than 50 thousand m^3 each. As expected, the low productivity wells have higher supply costs, while supply costs for the high productivity wells are relatively lower. These latter wells can be considerably more economically attractive for the operators. Most operators will have a mix of low and high productivity wells, as a normal result of exploration and development.

The Board's analysis indicates that the supply costs, in the field, range from a high of approximately \$270/m^3 for a well that produces 2 500 m^3 of heavy oil over its lifetime, to a low of \$35/m^3 for a well that produces 50 thousand m^3. For low productivity wells, a substantial reduction in supply cost is obtained as the production reaches or exceeds 10 thousand m^3. For a well that produces at least 10 thousand m^3, the supply costs average in the range of \$70 - \$80/m^3. For comparative purposes, the average posted price for May 2001 Bow River Heavy Blend crude oil at Hardisty, Alberta was \$167.56/m^3, while Lloydminster Heavy Blend at Hardisty received \$161.66. Costs of blending with diluent and cost of transportation must also be considered in making a valid comparison.

FIGURE 7.3

Upper Mannville – Well and Recovery Distributions

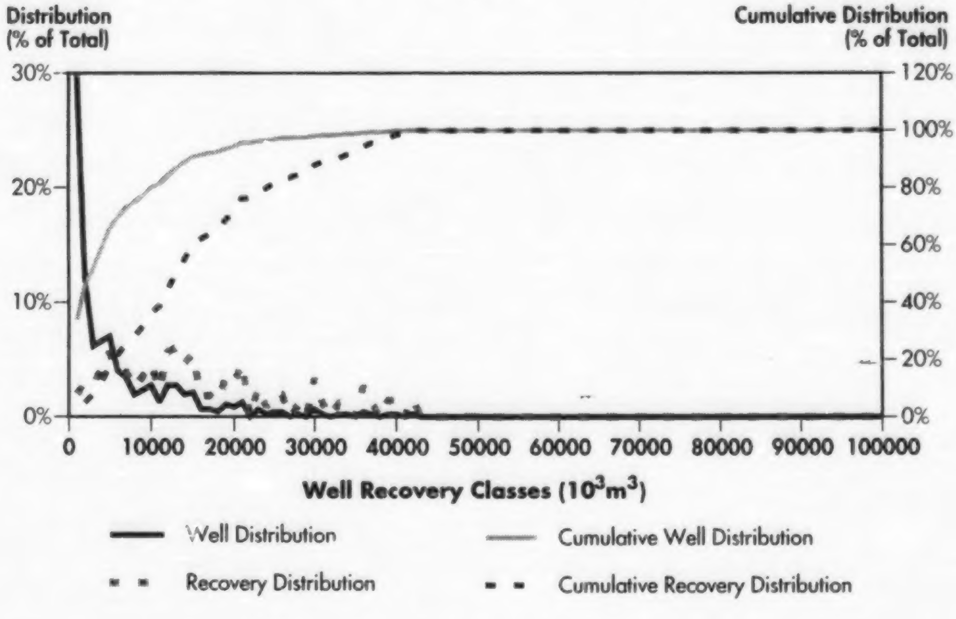
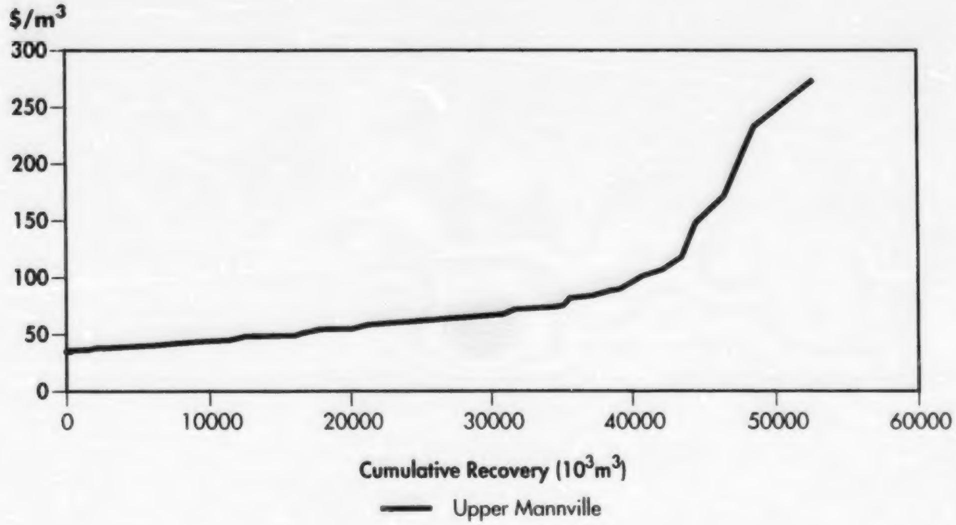


FIGURE 7.4

Supply Cost Curve – Upper Mannville



CHAPTER EIGHT

8. Other Minor Plays

The plays in this chapter contain relatively small amounts of oil in place that are characterized as heavy oil. Each play is named and defined, and the oil-in-place estimates are updated from year-end 1994 data for the discovered and undiscovered portions to year-end 1997 or 1998 depending on the province it is located. The Board did not conduct engineering or economic analyses on these plays.

8.1 Devonian Zones

8.1.1 Central Alberta Region

Leduc- Bashaw

The Leduc-Bashaw play includes oil pools within the Leduc Formation on the Bashaw reef complex, located between the Ricinus-Meadowbrook reef trend and the southern Alberta shelf. The Leduc reefs grew on the Cooking Lake Platform and are encased and sealed by the surrounding Duvernay and Ireton shales. Stratigraphic and structural-stratigraphic traps occur at the updip terminations of large reefs, downdip of re-entrants in reef complexes, and in isolated pinnacle reefs. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 4.0 million m^3 compared with 3.8 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 1.0 million m^3.

Wabamun Eroded Edge

The Wabamun Eroded Edge play is defined to include oil pools found in traps developed against the unconformity where Wabamun shelf carbonates subcrop beneath Cretaceous rocks. The play is bounded to the south by the transition to the Stettler evaporites, to the north by the Wabamun Peace River Arch play and to the west by the subcrop edge. These shallow water carbonate reservoirs commonly consist of partly dolomitized peloidal grainstones. Trapping is provided by the Cretaceous shales and by structural drape over deeper Leduc reefs. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 0.6 million m^3 compared with 0.5 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 0.4 million m^3.

8.1.2 Williston Basin Region

Leduc-Nisku Southern Alberta

The Leduc-Nisku play includes oil pools found in thick reef carbonates along the Leduc Formation barrier reef and those pools in the Camrose and Nisku carbonate shelves where they are draped over the Leduc topographical highs. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 13.5 million m^3 compared with 12.7 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 6.5 million m^3 of oil in place.

Arcs – Structural

The Arcs-Structural play includes oil pools found in structural and/or stratigraphic traps in the Arcs Member of the Nisku Formation. The Arcs is generally thin, but can reach 45 metres in thickness and consists of light coloured, fine to coarse-grained crystalline dolostone with bands of brown, granular dolomite and anhydrite. Hydrocarbons are trapped in the porous dolostones in structurally high closures which may be the result of salt solution on older Devonian evaporite sequences. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 5.3 million m^3 compared with 4.9 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 4.7 million m^3.

8.2 Triassic Zones

8.2.1 Peace River Embayment Region

Charlie Lake Carbonates

The Charlie Lake Carbonates play includes oil pools discovered in algal carbonates of the Charlie Lake Formation, in combination stratigraphic/structural traps in the area influenced by Peace River Arch/Embayment block faulting. The area is bounded by the transition to sandstone in the west and by the Charlie Lake erosional edge to the north, east and south. Pools are found in carbonate members where the principle trapping mechanism is the facies pinchout, erosional truncation and unconformity related traps. The structural component results from drape over older structures with enhanced porosity and permeability resulting from fractures. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 31.1 million m^3 compared with 27.8 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) to be 10.6 million m^3.

8.3 Jurassic Zones (First Columbian Clastic Wedge)

8.3.1 Alberta and British Columbia Region

Gilby – Medicine River Stratigraphic

The Gilby-Medicine River Stratigraphic play includes oil pools that occur in Jurassic and Lower Cretaceous sandstone, filling channels or valleys carved into the Paleozoic surface and sealed by impermeable Jurassic shales. The area is a narrow belt in south-central Alberta, trending north-northwest along the Jurassic erosional edge between Drayton Valley and Calgary. It involves a complex of erosional valleys and headlands with a variety of channel-fill units. Stratigraphically trapped pools produce oil from valley fill sands, isolated Jurassic sandstone headland remnants and sands draped over headland remnants. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 1.0 million m^3 compared with 0.9 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) to be 0.2 million m^3.

Nordegg

The Nordegg play includes oil pools that occur in Jurassic and Lower Cretaceous channel and valley fill sandstone and in Nordegg erosionally isolated shallow marine sandstones. The play limits are the Jurassic erosional edge to the east and south, the Nordegg Platform play to the west and the Nordegg shelf/basinal play to the northwest. This play involves a complex network of Jurassic and Cretaceous erosional valleys carved into Nordegg shoreline sandstone and underlying Mississippian carbonates. The valleys are filled with Lower Jurassic to Lower Cretaceous sandstones and shales called the J_1, J_2, and J_3 units. These form stratigraphic traps that may be commingled with underlying Carboniferous pools. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 5.7 million m^3 compared with 5.4 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) to be 7.3 million m^3.

8.4 Cretaceous Zones (Second Columbian Clastic Wedge)

8.4.1 Northwest Alberta and British Columbia Region

Bluesky

The Bluesky play includes the oil pools contained within the Bluesky Formation in northwestern Alberta and northeastern British Columbia. The Bluesky Formation was deposited as a series of regressive pulses during the southward transgression of the Boreal Sea. The three main facies present are: regressive coarsening-upwards offshore to shallow marine sandstone; transgressive conglomerate lags; and, incised valley fill deposits. There has been a significant volume of heavy oil added to the discovered total as a result of Nexen's (Wascana) Hay Field development in British Columbia. That field doubled the discovered in-place oil resource estimate to 12.3 million m^3. The NEB estimated the potential heavy oil resources to be 6.8 million m^3.

8.5 Upper Cretaceous (Colorado Group) Zones (Laramide Clastic Wedge)

8.5.1 Plains Region

Viking Transgressive

The Viking Formation has been sub-divided into three plays on the basis of sequence stratigraphy as defined by Reinson et al, 1995[1]. The three plays are the Regressive, Transgressive and Channel, which occur at different stratigraphic levels. Pools from more than one play type may be present in a particular area. The Transgressive play is the only one that contains heavy oil.

The Transgressive play is defined to include oil pools in sandstones and conglomerates deposited in transgressive sequences within the upper portion of the Viking Formation. The pools are usually found in sandbar deposits or in transgressive sheet sands. Most of the heavy oil pools are found in eastern Alberta in the Vulcan, Hairy Hill and Little Bow Fields. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 2.9 million m^3 compared with 2.6 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 1.2 million m^3.

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[1] Reinson, G.E., Lee, P.J., Olsen-Heise, K., Campbell, R.I., Holmstrom, G. and Gault, R.J., *Geological Play Definitions and Gas Resources, Lower Cretaceous Colorado Group, Western Canada Interior Plains* in *Proceedings of the Oil and Gas Forum 1995 - Energy From Sediments*, J.S. Bell, T.D. Bird, T.L. Hillier, and P.L. Greener (eds), GSC Open File 3058.

8.6 Summary

These plays, containing minor amounts of heavy oil, provide an additional source of conventional heavy oil supply (Table 8.1). While the heavy oil portion may not provide an identifiable exploration target, these plays have some potential in the future.

TABLE 8.1

Resources of Other Minor Plays (10^6m^3)

Play	Discovered		Undiscovered
	GSC 1994	NEB 1998	NEB 1998
Leduc-Bashaw	3.8	4.0	1.0
Wabamun Eroded Edge	0.5	0.6	0.4
Leduc-Nisku Southern Alta.	12.7	13.5	6.5
Arcs-Structural	4.9	5.3	4.7
Charlie Lake Carbonates	27.8	31.1	10.6
Gilby-Medicine R. Strat.	0.9	1.0	0.2
Nordegg	5.4	5.7	7.3
Bluesky	6.2	12.3	6.8
Viking Transgressive	2.6	2.9	1.2
Total	**64.8**	**76.4**	**38.7**

CHAPTER NINE

9. Summary and Conclusions

During its preparation of the 1999 Supply and Demand Report, the Board relied on an assessment of conventional oil resources in the WCSB, published by the GSC in 1998, based on year-end 1994 data. At that time, the Board believed that its supply projection for conventional heavy oil was being unduly constrained by an underestimation of the size of the heavy oil resource base. Subsequently, the Board undertook to re-assess the conventional heavy oil resources in the WCSB, in preparation for the next Supply and Demand Report, targeted for release in 2003.

The Board decided to update its assessment of the discovered oil-in-place volumes of conventional heavy oil in the WCSB, to year-end 1998 (1997 for Saskatchewan), and have the GSC run the revised data in its discovery process model. The new reference dates allowed for the capture of new information from the large number of oil wells drilled in 1996 and 1997. Following the recommendation of the GSC, the Board used a different computer model, the geo-anchored method, to project the undiscovered resource base rather than using the results obtained from the PETRIMES model previously used by the GSC. This new method required the input of both the light and heavy oil-in-place data for the studied zones.

The Board's review of these resources focussed on three distinct geological zones which contain the bulk of conventional heavy oil in Western Canada: the Carboniferous; the Jurassic; and the Cretaceous. The Carboniferous zone has seven geological plays that contain heavy oil and comprise about 18 percent of the heavy oil in place. Since the last review by the GSC, the total oil-in-place volume, both light and heavy oils, for these seven plays has increased from 2 858 million m^3 to 4 211 million m^3 (18.0 to 26.5 billion barrels), with heavy oil accounting for one-third of that increased volume.

The Jurassic zone has three geological plays that contain heavy oil, comprising about 11 percent of the heavy oil in place in Western Canada. Since the last GSC review, the total oil-in-place volume, both light and heavy oils, for these three plays has increased from 533 million m^3 to 889 million m^3 (3.4 to 5.6 billion barrels), with heavy oil accounting for almost all of that increase.

The Cretaceous zone has nine geological plays that contain heavy oil, comprising almost 70 percent of the heavy oil in Western Canada. The total oil-in-place volume, for both light and heavy oils since the last review by the GSC, for these nine plays has increased from 5 408 million m^3 to 7 020 million m^3 (34.0 to 44.2 billion barrels), with heavy oil accounting for 80 percent of that increased volume.

In total, the oil-in-place volumes of light and heavy oils for all plays in the studied zones has grown from 8 798 million m^3 to 12 120 million m^3 (55.3 to 76.2 billion barrels), an increase of 38 percent. Conventional heavy oil comprises about 65 percent of the NEB's total oil-in-place volume for the studied zones. While a significant portion of the growth is due to the inclusion of the miscellaneous pool information from Saskatchewan and the Manitoba data, there has also been growth in the existing pools and new discoveries made. There were a total of 614 new pools discovered in the studied zones between year-end 1994 and year-end 1997/98.

The Board's analysis for conventional heavy crude oil indicates that the oil in place for the studied plays has increased by about 20 percent, to 7 927 million m^3 (49.9 billion barrels), from the estimate of 6 575 million m^3 (41.4 billion barrels) provided in the Board's 1999 Supply and Demand Report. The results of the Board's new assessment are shown in Table 9.1. This increase can be attributed to the fact that this study projects the existence of a significantly greater number of smaller-sized pools compared with previous studies.

The Board's analysis of the heavy oil pools indicates that there is a significant amount of heavy oil left to be found in the studied zones in the provinces of British Columbia, Alberta and Saskatchewan. For the most part, the undiscovered pools are expected to be smaller than the discovered pools; however, there are still a few large pools projected to be found. The discovery of these large pools may require development of a new exploration strategy. As well, some of the larger pools may already be found but not yet recognized, while some of these larger pools may result from the future amalgamation of a number of smaller recognized or miscellaneous pools, after aggressive pool extension drilling.

In order to estimate the portion of the oil-in-place volumes that could be recovered, a large amount of production and performance data for heavy oil wells was analysed. Recovery factors assigned to the undiscovered pool population were based on analogy with similar sized already-discovered pools. For each zone and play, wells were grouped into respective categories, based on their estimated total recovery volumes. Typical well performance profiles, developed for these groups, were then used in determining supply costs. These supply costs estimates were subsequently used to determine the volume of economically recoverable resources.

This study estimates that 21 percent of the discovered resources, and 12 percent of currently undiscovered resources, can be technically recovered (Table 9.1). These estimates include the contributions from the application of present day, proven technology and production practices, and the potential for improved recovery through the application of future technologies. The ultimate recoverable resources of heavy conventional crude oil in Western Canada are thus estimated to be some 1 391 million m^3 (8.8 billion barrels), an increase of 8.5 percent compared with the Board's 1999 Supply and Demand Report.

Supply cost curves were generated for each geological play, and, in general, the Jurassic plays have the lowest costs while the Cretaceous plays have the highest. Among individual plays, the Jurassic Shaunavon play has the lowest mean supply cost at \$38/m^3 (\$6.04/bbl) and the Carboniferous Souris-Tilston play has the highest at \$125/m^3 (\$19.87/bbl). A review of supply costs considered in aggregate, suggests that 65 percent of the technically recoverable volume can be recovered economically at a price point of \$62.38/m^3 (\$9.91/bbl) in the field, or 80 percent at \$83.91/m^3 (\$13.02/bbl).

Considering these supply costs in relation to recent prices for heavy crude oil, with May 2001 Bow River Heavy Blend crude oil at Hardisty, Alberta posted at \$167.56/m^3 (\$26.64/bbl), and Lloydminster Heavy Blend at Hardisty at \$161.66/m^3 (\$25.70/bbl), heavy crude production would seem relatively attractive for most plays. Costs of blending with diluent and cost of transportation must also be considered.

This assessment of heavy oil resources, given the test of time, will likely prove to be somewhat conservative. Past experience suggests this will be the case, perhaps due to the inherent conservative nature of resource estimation by statistical analysis. More specifically, the Board acknowledges that its own process for the largest conventional heavy oil play, the Cretaceous Colony to Lloydminster play, results in a more conservative estimate. Grouping seven horizons that could potentially be assessed as seven separate plays into one play results in a lower overall assessment.

TABLE 9.1

Summary of All Zones, Heavy Oil Only

Metric ($10^6 m^3$)

Zone	Oil In Place		Recoverable			
	Discovered	Undiscovered	Discovered			Undiscovered
			Established Reserves	Remaining Reserves	Future Improved Recovery[1]	Undiscovered Recoverable[1]
Carboniferous	801.7	612.2	108.1	33.8	53.2	82.8
Jurassic	545.1	336.2	149.9	28.6	28.6	50.7
Cretaceous	3 608.6	1 907.7	422.3	126.8	291.0	204.3
Other	76.4	38.7	n/a	n/a	n/a	n/a
Total	5 031.8	2 894.8	680.3	189.2	372.8	337.8
	Total Oil In Place = 7 926.6		Total Recoverable = 1 390.9			

Imperial - (million barrels)

Zone	Oil In Place		Recoverable			
	Discovered	Undiscovered	Discovered			Undiscovered
			Established Reserves	Remaining Reserves	Future Improved Recovery[1]	Undiscovered Recoverable[1]
Carboniferous	5,042	3,850	680	213	335	521
Jurassic	3,428	2,114	943	180	180	319
Cretaceous	22,665	11,982	2,656	797	1,830	1,285
Other	481	243	n/a	n/a	n/a	n/a
Total	31,616	18,189	4,279	1,190	2,345	2,125
	Total Oil In Place = 49,805		Total Recoverable = 8,749			

[1] Both components of future improved recovery are included (ie. that from current technology and optimization plus that from the implementation of future technologies) for both discovered and undiscovered pools.